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JET PROPULSION LABORATORY

CALIFORNIA INSTITUTE OF TECHNOLOGY

PASADENA, CALIFORNIA

APPENDIX A

MISSION ANALYSIS AND PERFORMANCE SPECIFICATION STUDIES REPORT

PREPARED FOR:

JET PROPULSION LABORATORIES

CONTRACT NUMBER 955189

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1. INTRODUCTION

This report presents the results of Task 1, Mission Analysis and Performance Specifications, of the Near Term Hybrid Passenger Vehicle Development Program, Phase I. The work was performed by South Coast Technology, Inc., with assistance from General Research Corp. (GRC). GRC was assigned the task of defining missions, developing distributions of daily travel and composite driving cycles for these missions, providing information necessary to estimate the potential replacement of the existing fleet by hybrids, and estimating acceleration/gradeability performance requirements for safe operation. GRC's report on these results is presented in its entirety in Appendix A1 of this report.

South Coast Technology utilized the data supplied by GRC to develop mission specifications, define reference vehicles, develop hybrid vehicle performance specifications, and make fuel consumption estimates for the reference vehicles.

2. ASSUMPTIONS AND METHODOLOGY

2.1 General Approach

The major assumptions which underly the approach taken to the mission analysis and development of performance specifications are the following:

- The daily operating range of a hybrid vehicle should not be limited by the stored energy capacity.
- The performance of a hybrid vehicle should not be strongly dependent on the battery state-of-charge.

These two assumptions were made for several reasons. First of all, a vehicle which satisfies these properties and which has greatly reduced petroleum consumption is technically feasible if it incorporates a suitable multi-modal control strategy. Secondly, if a hybrid vehicle is to have the potential for making a substantial impact on fleet petroleum consumption, it must be saleable in large numbers and, consequently, must offer the same flexibility and utility as a conventional automobile, at least for the near term. Any fundamental restriction such as a limitation on the operating range before battery recharge is required, or limited performance under certain operating conditions, will restrict sales, particularly in the case of a 5 or 6 passenger vehicle whose purchase price will almost certainly be higher than that of a conventional counterpart.

In short, the design approach which SCT will be taking results in a general purpose sedan whose potential usability for a given mission is generally not restricted by the driving patterns associated with that mission. The only exceptions to this would occur for missions in which there is an extremely high performance requirement, e.g., trailer-towing, police patrol work, and so forth.

Our general approach in this mission analysis was, consequently, to identify whatever distinct usage patterns (missions) exist for such general purpose automobiles, identify the performance and accommodation requirements associated with these missions, and characterize the travel distributions and driving cycles which can be used as a basis for estimating fuel consumption on these missions. Special purpose vehicles (e.g., limited range 'commuter' vehicles), which do

not in actuality exist in today's market, were not considered in the study.

2.2 Mission Identification

The approach taken in identifying and characterizing distinct missions involved identifying various usage patterns, and also identifying requirements regarding passenger and luggage accommodations, as perceived by the owner.

2.2.1 Distributions of Daily Travel

The data sources and methodology used in identifying distinct usage patterns and developing the corresponding distributions of daily travel are explained in the GRC report (Appendix A1). Three distinct usage patterns were identified, corresponding to 'primary', 'secondary', and 'only' drivers. (Previous examination of the travel data has led to the division of drivers into three groups with widely differing travel patterns: primary, secondary, and only drivers. No other groups of drivers were clearly distinguishable on the basis of their reported travel. Primary and secondary drivers are from multi-car, multi-driver households, where the primary driver is defined as the driver who travels the greatest distance each day. Secondary drivers are the other drivers at multi-driver households. The only driver is from a one-car, one-driver household.) Travel distribution data for these three mission types were obtained for two areas: Washington, D. C. and Los Angeles. These travel distributions are not, however, directly usable in making fuel and energy consumption estimates for the near term hybrid since the annual driving distance derivable from these distributions is not the same

as that specified in the JPL-supplied Assumptions and Guidelines. The methodology used in correcting these distributions to something usable was the following.

As mentioned in the GRC report, the 'only' driver data is very close to being the average between 'primary' and 'secondary' driver data. In view of the definition of 'primary' and 'secondary' drivers, there are at least as many 'secondary' drivers and cars as 'primary' drivers and cars. Moreover, the number of cars in the average multi-car household is not much over two, which implies that the number of 'primary' cars is not much different than the number of 'secondary' cars. (See, for example, Table 2.1 in Section 2.4.1) Consequently, the average annual distance travelled by all primary and secondary cars is not much different from the average annual distance travelled by the 'only' car; and, hence, the average annual distance for all cars is not much different than the 'only' cars. On this basis, then, what was done was to adjust the 'only' driver data for Washington and Los Angeles to obtain the annual distance projected by JPL for the year 1990, which is the midpoint of the expected 10-year life of a 1985 model year production vehicle. That is, if

D_{1990} = average annual distance projected by JPL for 1990,

$D_{o,w}$ = average annual distance for 'only' driver from Washington, D. C. data,

$D_{o,la}$ = average annual distance for 'only' driver from Los Angeles data,

then adjustment factors

$$C_w = D_{1990}/D_{o,w}$$

$$C_{la} = D_{1990}/D_{o,la}$$

were computed, and the driving distance column of Table 2.1 of Appendix A was multiplied by a factor of C_w for the Washington data, and C_{la} for the Los Angeles data. The adjusted data from columns 'A' was then plotted on the same coordinates for Washington and Los Angeles, and average curves for the travel distribution of only, primary, and secondary drivers were plotted through the combined Washington/LA data points. These curves are shown in Figure 2.1. These curves constitute the basic daily travel data to be used in estimating the fuel and energy consumption of the reference and hybrid vehicles.

In addition to the above three missions identified for general purpose automobiles, a fourth possible 5-6 passenger hybrid vehicle application is that of a taxi, characteristics of which are summarized in Section 6 of Appendix A1.

2.2.2 Payload (Passenger and Luggage Accommodation)

The missions identified above do not have distinctly different payload requirements; rather, the required payload depends on the preferences of the individual owner involved. The word 'preferences' must be emphasized. Although it is clear that the payload requirements for nearly all trips for each of the missions described previously could be met by a 5 passenger vehicle (see, for example, Table 3.2 of Appendix A1), it is also true that a large portion of the driving public will opt for the largest vehicle which is economically feasible for them, regardless of what their 'objective' payload requirements might be.

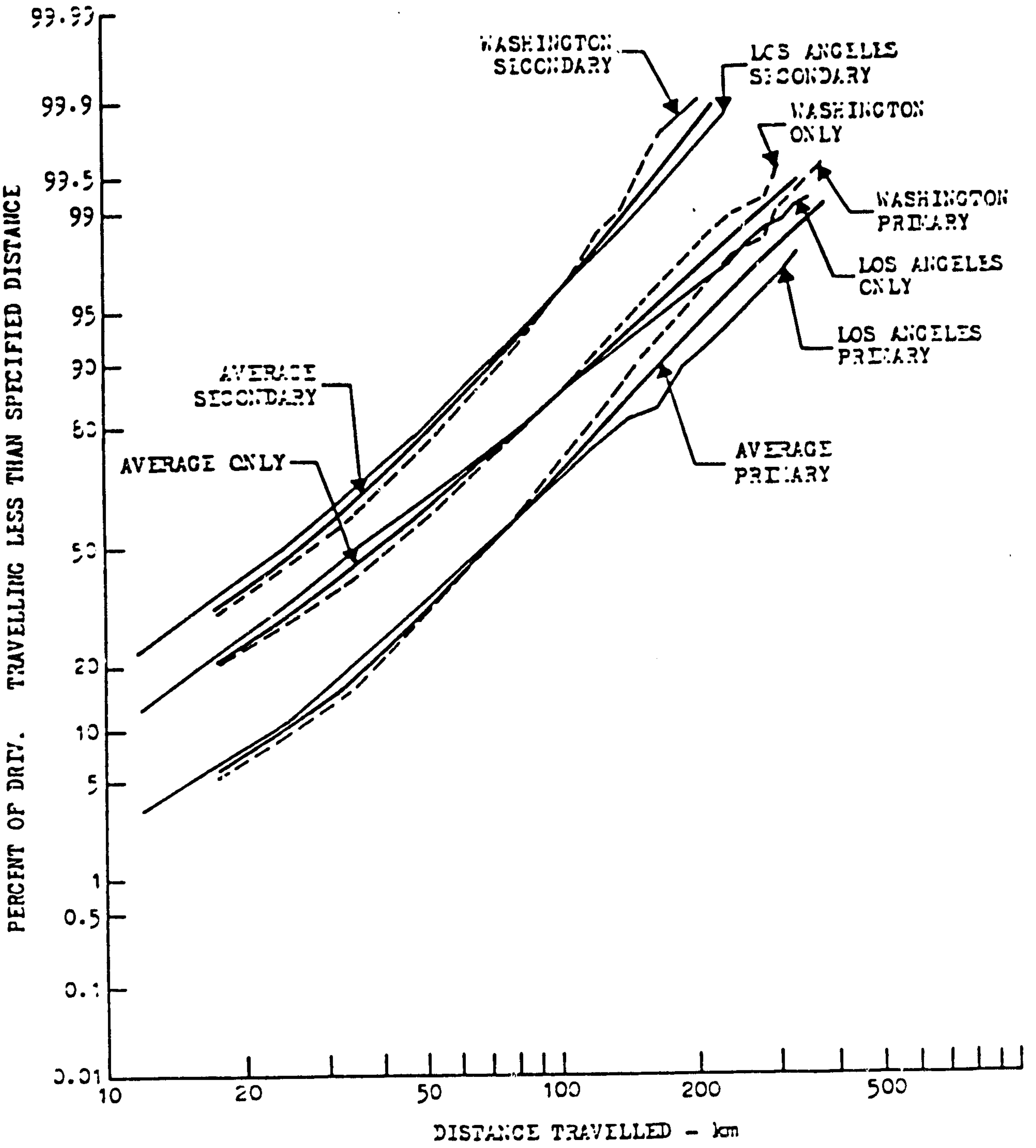

Figure 2.1 Travel Distribution Adjusted to JPL Projection of 1990 Average Annual Vehicle Travel

For these reasons, it is reasonable to include driver preference as to vehicle size as part of the mission definition; that is, the mission consists of a usage pattern for the vehicle together with a perceived payload requirement. The methodology here (which will be discussed further in connection with the definition of reference vehicles) was to represent the range of 5-6 passenger vehicles by two typical vehicles. One of these is a 5 passenger (or tight 6 passenger) package, and the other, a package which has comfortable room for 6 passengers and has more luggage room. In terms of a volume-based size classification such as EPA uses, the former would be representative of the range from 'compact' through the lower portion of the 'midsize' class; the latter, the upper portion of 'midsize' and the 'large' class. The two sizes would also represent the JPL weight-based classification from the 'compact' through the 'large' class. This, then, leads to the definition of eight distinct missions: only, primary, and secondary drivers, and taxi usage patterns, each with different perceived requirements for passenger/luggage accommodations, which we will denote by 'tight' and 'roomy'. In view of the contraction of the overall size range of passenger vehicles which is occurring as a result of downsizing, we saw no reason to attempt any finer size breakdown than the 'tight' and 'roomy' classifications for the range consisting of 5 and 6 passenger cars.

2.3 Trip Characteristics and Composite Driving Cycle

Apart from the distribution of daily travel, the only characteristic of usage patterns which is relevant to the problems of estimating fuel and energy consumption and life cycle cost is the

distribution of driving speeds as a function of daily travel. Data on travel speed, amount of freeway travel, and so forth, are given in Sections 2.3 and 2.4 of Appendix A1; and the construction of a composite driving cycle, which is a function of the daily travel, is described in Section 7 of Appendix A1.

Data on trip frequency, average trip distance, and trip purpose was also obtained; sources, methodology, and results are summarized in Sections 2.2 and 3.1 of Appendix A1. These data are of primarily academic interest, however. For example, consider a day on which the driver travels 100 km. The distribution of driving speeds for such a 100 km day is represented by a composite driving cycle represented by a weighted sum of the SAE J227(a)B, urban and highway driving cycles. The number of trips into which this 100 km is subdivided is relevant to the fuel consumption only as it affects the following:

- Shutdown time of the heat engine between trips, and consequent degradation of fuel consumption during warmup periods.
- Opportunities for recharging batteries during the day and consequent improvement in fuel consumption due to increased use of wall plug energy.

Unfortunately, there is nothing in the available data which would allow one to estimate the distribution of time intervals between trips, the availability of recharge facilities during such time intervals, or the likelihood that the driver would utilize such facilities if they were available. Furthermore, the engine modelling techniques we have at our disposal do not include simulation of an

engine at anything other than normal operating temperature; so, with respect to the warmup problem, it is not clear what we could do with the additional data even if it were available.

For these reasons, mission specification M3 (trip lengths, trip frequency, and trip purpose) has no impact on the analysis and the design of the hybrid vehicle. We have, consequently, omitted these from the mission specifications in Section 3 of this report and replaced them with the single assumption that batteries will be recharged once a day, regardless of the distance travelled during that day (provided, of course, the distance is greater than zero).

2.4 Potential for Replacement by Hybrid Vehicles

In attempting to estimate the potential number of vehicles engaged in performing each of the defined missions which could be replaced by hybrid vehicles, it is necessary to consider the following:

- The number of vehicles in the 1985 fleet corresponding to each defined mission; i.e., usage pattern and size classification.
- Restrictions on an individual's ability to effectively operate a hybrid vehicle resulting from peculiar characteristics of the hybrid; in particular, the need to recharge batteries.
- The impact of such restrictions on the number of vehicles in each mission.

Knowledge of these factors allows one to estimate the maximum potential replacement by hybrid vehicles. However, it is a reality that the manufacturing cost of a hybrid will be higher than that of

a conventional vehicle and that, as a consequence, the retail price will almost certainly be higher; this will restrict the potential replacement by hybrids, in each mission, by an amount which will depend on the mission. In the real world, then, it is also necessary to consider the following additional factors:

- Probable pricing policies of manufacturers for fuel efficient vehicles vis-a-vis conventional vehicles.
- Elasticity of the market, within each mission, with respect to the retail price.
- Impact of energy prices on the new car buying decision.
- Consumer perception of breakeven operating costs of hybrids vs. conventional cars; i.e., not only the hard fact calculation, but the way in which consumers would view much higher prices for petroleum products.
- Consumer perception of availability of petroleum products, the potential for rationing, and shortages.

2.4.1 Number of Vehicles Corresponding to Each Mission

Section 4 of Appendix A1 provides a discussion of the methodology and results obtained in estimating the number of vehicles associated with each usage pattern; i.e., primary, secondary, and only driver. The results are summarized in Tables 4.5 and 4.6 of Appendix A1. If we adjust the data in Table 4.5 for the unaccounted-for 3% of private cars, assuming that the 3% are divided between urban and rural in the same proportion as the data in the table (i.e., .70 urban, .271 rural), we get a 72/28% split between urban-based cars and rural-based cars. Applying this proportion to

Table 4.6, we find that the percentages of all private cars associated with the three usage patterns is as given in Table 2.1.

Table 2.1. Distribution of Cars Relative to Usage Patterns

	At Single Family Units	At Multi-Family Units
Secondary Cars	27.3	6.1
Only Cars	25.0	13.8
Primary Cars	22.3	5.5

The next question involves how these numbers split up relative to the two size classes 'tight' and 'roomy'. To approach this, we made the assumption that the 'tight' package is representative of the 'compact' size class and half of the 'full size' class; and the 'roomy' package is representative of the remainder of the 'full size' class, and the 'large' class, where 'compact', 'full size', and 'large' are weight based classifications as given in Table C-1 of the Assumptions and Guildelines provided by JPL. Using the projections for 1985 given in the same Table C-1, the 'tight' package is representative of 45% of the 1985 new car fleet; and the 'roomy' package is representative of 30%. The corresponding values for the 1976 fleet are 45.8% and 40.3%. For the sake of simplicity, then, we assumed 'tight' cars at a constant 45% of the new car fleet and 'roomy' cars at 40% in 1976 declining linearly to 30% in 1985. Using the total fleet projections given in Table A-2 of the Assumptions and Guidelines, and assuming a 10% per annum retirement rate, we find that of the total fleet in 1985, 45% is represented by the 'tight' car class,

and 35% by the 'roomy' car class. Assuming that the breakdown by car size of the new car fleet remained constant with the 'large' class at 15% of the new car fleet past 1985, then our 'roomy' class would eventually decline to 30% of the total fleet by 1995. There is also the distinct possibility that, with the availability of highly fuel efficient cars in the 'roomy' class, such as hybrids, this class would recapture some of its traditional market in the USA; thus, an assumption that the number of cars in the total fleet in the 'roomy' class remains constant at 35% past 1985, with the advent of hybrids in sufficient numbers, would also be tenable.

Assuming that these size classes are uniformly represented in the 'primary', 'only', and 'secondary' usage patterns, and also, that they are uniformly distributed among car owners in single and multi-family dwellings, we get the numbers shown in Table 2.2 for the distribution of cars in the 1985 fleet.

Table 2.2. Distribution of Cars Relative to Usage Patterns and Size Classification

		At Single Family Units	At Multi-Family Units
Secondary Cars	Tight	12.3	2.7
	Roomy	9.6	2.1
Only Cars	Tight	11.2	6.2
	Roomy	8.8	4.8
Primary Cars	Tight	10.0	2.5
	Roomy	7.8	1.9

The two assumptions made in deriving the distribution in Table 2.2 need some discussion. The assumption that the two size classes are uniformly represented in the three usage patterns is probably not too far off. A large number of cars start their lives as 'primary' cars in a multi-car household, and then get shifted into the secondary role when they start accumulating high mileage. This is reflected in the fact that a car's annual mileage decreases as it gets older (as exemplified in Table C-3 of the Assumptions and Guidelines). In households which follow such a pattern, the 'secondary' car is just as likely to fall into the 'tight' or 'roomy' size class as is the 'primary' car. There are, however, those cases in which the 'secondary' car is bought specifically for that type of use, generally as a used car; and these may tend to bias the secondary car size distribution somewhat in the direction of the 'tight' size class. Within the limits of accuracy of what we are doing here, however, the assumption is warranted (particularly since hard data to the contrary does not exist). The second assumption, that the distribution is uniform relative to the type of dwelling, was also made in the absence of other data. Again, there may be a slight bias, which we are neglecting, in the direction of a larger percentage of the 'tight' size class cars owned by individuals in multi-family dwellings than by those in single family dwellings.

2.4.2 Restrictions on the Applicability of Hybrids for Each Mission

The extent of application of hybrids in each of the defined missions may be limited by several factors. Apart from price-related factors, which will be discussed in Section 2.4.3, the major factor

which will limit the potential replacement of conventional vehicles by hybrids is the availability of recharge facilities. To quantify this limitation, we made the assumption that the electrical service required for recharge would be available if, and only if, off-street parking facilities are available. This assumption may be a bit conservative since there is a possibility that a utility would be willing to install curbside service for someone without off-street parking but with an essentially fixed curbside parking location. However, particularly for the near term, the assumption made is a safe one. A further discussion of the sources and methodology used to obtain a distribution of the availability of off-street parking relative to the usage patterns is given in Section 4 of Appendix A1.

A problem occurs when we attempt to further detail this distribution to include the size class of the car. As Table 4.3 of Appendix A1 indicates, there is a positive correlation between income and the availability of off-street parking (garage/carport) for owner-occupied housing, although no such correlation appears to exist for rental units.

It should be noted that the lack of correlation between income and off-street parking for rental units is surprising and very much at odds with the experience of anyone who has lived in a major inner city area, such as New York, Chicago, or San Francisco. However, the correlation is clear for owner-occupied housing, so we will concentrate on that.

Consequently, if there is also a positive correlation between income and the size of car, we would expect that a larger fraction

of the 'roomy' cars would have off-street parking (hence, recharge facilities) available than of the 'tight' cars.

Information on the breakdown of the automobile market by car size (value) and by income class is obtainable from survey results of the University of Michigan, Survey Research Center. Apparently, such information has not been published by the Survey Research Center itself, but some results from the 1967 survey are available in a Ph.D. dissertation done at the University of Michigan by W. H. Peters (1968).(1) Peters' analysis of the 1967 Survey Research Center data shows that 79% of the large cars and 64% of the medium-sized cars were purchased by high income individuals.(2) The tabulation is shown in Table 2.3. Peters "overprivileged" income status refers to those whose incomes were above the median for their occupations, i.e., high income individuals. These data (Table 2.3) refer to all families. A similar breakdown of the automobile market by income class for single-car families is shown in Table 2.4. Here 71% of the large car market and 53% of the medium-sized car market are comprised of high income individuals.

A second source of information on the question of car size (value) is the survey information collected by the U. S. Bureau of Labor Statistics to calculate the new Consumer Price Index (1977 base). The information with regard to automobile expenditures by

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(1) Peters, William Henry. Variation in Consumer Buying Behavior: An Analytical Study of Automobile Purchases. (Unpublished Ph.D. dissertation, Business Administration, Univ. of Michigan, 1968)

(2) Ibid., p. 59

Table 2.3. Make Up of Automobile Markets by Total Family Income Status. (1967 Data - All Families)

Income Status	No Car N=807	Used Car N=414	Smaller Car N=489	Medium Sized Car N=667	Large Car N=76	Totals N=2453
	Automobile Class					
Underprivileged	64%	30%	26%	17%	9%	36%
Average	15	20	25	19	12	19
Overprivileged	21	50	49	64	79	45
TOTALS	100%	100%	100%	100%	100%	100%

Table 2.4. Make Up of Automobile Markets by Total Family Income Status. (1967 Data - Single Car Families)

Income Status	Used Car N=195	Smaller Car N=256	Medium Sized Car N=345	Large Car N=32	Totals N=828
	Automobile Class				
Underprivileged	41%	39%	25%	13%	32%
Average	22	27	22	16	23
Overprivileged	37	34	53	71	45
TOTAL	100%	100%	100%	100%	100%

income class is shown in Table 2.5.[3] The relevant information on new car purchases in 1972 and 1973 are shown in Table 2.6 and 2.7.

In attempting to convert this data to data involving our tight and roomy classification, we made the following assumptions:

- Compact and intermediate classes are represented by the 'tight' class, with compacts and intermediates equally represented. (For example, in 1978, sales of compacts and intermediates were 2.6 million and 3 million.)
- Standard, medium, and luxury classes are represented by the 'roomy' class, in the proportions .385, .385, .23. These proportions are based on 1978 sales of 2.1 million in the MVMA 'standard' class and .64 million in the luxury class. The MVMA classes do not include a 'medium' class; it was assumed that the medium and standard classes referred to in Table 2.7 comprise the MVMA 'standard' class, and are equally represented therein.

Under these assumptions, Table 2.8 was constructed from Table 2.7. Also shown in Table 2.8 is the estimated fraction of owner-occupied housing units, in the given income category, with off-street parking, based on the data on Table 4.3 of Appendix A1.

(3) U. S. Department of Labor, Bureau of Labor Statistics. Consumer Expenditure Survey Series: Interview Survey 1972 and 1973, (Report 455-1, 1976)

Table 2.5 Average Annual Motor Vehicle Purchases and Selected Maintenance and Repair Expenditures, by FAMILY INCOME

(All urban and rural families and single consumers, United States, Consumer Expenditure Interview Survey, 1972 and 1973)

Expenditure item	Total (1972)	Family income before taxes, 1972: $0 to $3,499	$3,500 to $6,899	$6,900 to $10,499	$10,500 to $15,199	$15,200 and over	Total (1973)	Family income before taxes, 1973: $0 to $3,499	$3,500 to $6,899	$6,900 to $10,499	$10,500 to $15,199	$15,200 and over
Number of families in universe (thousands)	70,788	15,485	12,565	12,500	13,745	16,493	71,652	14,124	12,124	12,071	13,302	20,031
Automobiles, total[1]	$615.19	$278.19	$342.10	$568.31	$792.54	$1,030.68	$669.39	$332.19	$322.49	$545.54	$750.90	$1,199.99
Domestic, total[1]	539.34	221.10	298.29	497.48	715.90	907.50	570.26	285.39	264.94	463.05	655.07	945.10
New, total	323.70	136.55	148.41	253.40	401.40	625.43	352.84	189.46	136.09	274.18	389.62	621.78
Subcompacts	27.29	14.69	23.94	16.60	29.92	47.76	33.88	13.88	16.64	27.67	30.01	44.97
Compacts	42.32	17.05	35.80	38.95	60.38	58.77	59.61	32.37	26.26	58.12	60.78	99.19
Intermediates	57.95	21.71	22.38	57.55	68.38	111.06	65.45	45.38	34.00	53.62	97.31	85.01
Standard	55.96	18.32	16.20	43.47	91.20	102.06	49.14	29.08	25.39	44.47	52.78	77.95
Medium	56.28	14.56	15.65	44.80	74.77	120.07	46.14	22.62	[2]5.52	34.34	37.56	90.95
Luxury	11.61	[2]11.16	[2]4.40	[2]6.93	[2]3.60	27.75	11.73	[2]4.76	[2]8.32	[2]1.42	[2]3.20	30.37
Specialty	25.14	14.20	[2]6.84	[2]10.93	22.97	61.79	47.09	25.65	[2]9.27	24.79	59.50	79.44
Miscellaneous	47.15	22.76	23.11	34.17	50.19	95.76	39.80	15.08	10.09	29.73	46.32	76.42
Used, total	239.05	85.17	148.27	231.98	305.57	274.73	212.22	95.83	126.09	186.37	262.14	329.57
Subcompacts	6.20	[2]2.26	[2]5.76	[2]4.75	[2]3.96	13.24	8.64	[2]4.01	[2]3.47	[2]5.05	11.78	14.59
Compacts	11.42	5.23	9.51	16.99	16.08	10.64	13.08	4.74	9.71	11.78	17.55	18.76
Intermediates	23.92	7.08	23.07	22.08	35.86	31.96	26.85	13.67	17.23	25.62	36.66	34.33
Standard	34.83	14.24	23.42	50.09	55.46	34.32	32.76	14.26	11.66	28.56	42.94	53.04
Medium	23.49	9.77	6.00	35.51	38.29	28.37	26.18	6.20	15.47	18.75	38.42	43.17
Luxury	7.52	[2]3.06	-	[2]4.92	[2]8.52	18.64	7.75	[2]9.22	[2].98	13.16	[2]2.84	10.07
Specialty	23.16	8.22	9.77	22.49	25.43	46.17	27.04	18.32	12.70	22.47	21.96	53.73
Miscellaneous	78.51	35.33	70.75	75.14	121.99	91.36	69.92	32.61	54.87	60.78	90.07	97.92
Imports, total[1]	75.85	55.09	43.81	70.83	76.64	123.18	99.33	46.80	57.55	82.67	95.49	170.41
New, total	45.09	33.51	24.47	42.04	39.17	79.01	65.67	29.59	31.02	51.60	61.49	119.45
Country of origin:												
Germany	18.17	11.36	12.10	17.39	10.78	35.83	23.94	[2]6.19	[2]12.05	18.77	18.70	59.14
Japan	17.12	12.95	10.15	16.13	17.85	28.12	30.48	17.54	14.02	25.07	33.89	50.21
All other	9.80	[2]9.20	[2]2.22	10.51	10.55	15.06	11.25	[2]5.87	[2]5.75	13.02	[2]9.91	19.99
Used, total	28.43	20.53	17.18	28.79	33.71	39.74	32.44	17.21	25.40	24.03	32.29	52.40
Trucks, total[1]	65.16	14.04	26.07	69.09	95.09	115.46	67.93	21.53	35.83	54.21	93.67	111.96
New, domestic	44.39	6.89	20.08	44.75	62.39	83.11	38.35	6.98	20.27	29.80	52.04	67.52
Used, domestic	17.59	5.73	4.16	18.56	27.83	29.81	24.46	10.40	11.21	21.47	32.60	30.71
Campers	17.35	5.77	4.41	5.77	17.25	[2]47.03	25.40	5.20	5.70	13.64	34.53	52.78
Motorcycles	11.83	3.66	6.08	13.78	17.47	[2]17.41	19.52	9.97	9.16	15.23	27.77	29.71
Selected repairs and maintenance:												
Tires and tubes	55.57	20.94	35.43	55.01	70.45	91.30	57.22	23.36	32.32	52.46	60.73	91.25
Batteries	7.90	3.57	6.19	8.57	10.21	11.22	7.96	3.75	6.33	7.90	9.64	10.07
Brake adjustment and repairs	9.24	3.89	5.56	8.94	11.31	15.53	9.11	3.45	6.18	7.70	12.43	13.41
Front end repairs	4.82	1.82	2.91	4.40	6.50	8.01	6.08	3.44	3.95	5.33	7.31	8.57
Exhaust system repairs	6.73	2.28	4.68	7.21	8.62	10.54	7.15	3.10	5.54	6.00	8.41	10.91
Clutch and transmission repairs	8.31	4.04	6.45	8.87	10.63	11.30	8.92	3.52	5.60	8.93	11.30	13.94
Shock absorbers	2.90	.96	1.64	2.62	4.25	4.82	2.76	1.07	1.42	2.79	3.81	4.50
Motor repair and replacement	18.82	8.26	11.22	17.34	23.25	32.07	21.70	8.11	10.57	20.27	22.33	33.55
Gasoline, total, all vehicles	332.81	147.32	225.24	333.64	424.39	511.70	376.25	186.27	217.13	339.75	459.10	539.10

[1] Includes small amount of "New or Used Not Reported; the total for trucks also includes a small amount for imports."

[2] Represents less than 5 sample families and is likely to have large sampling error.

Table 2.6 - Percent New Domestic Car Purchases by Income Class (1972)

Income	Subcompact	Compacts	Intermediate	Standard	Medium	Luxury	Specialty	Misc
0-3499	11.7	8.8	8.2	7.2	5.7	21.0	12.4	10.5
3500-6899	15.5	15.0	6.9	5.1	4.9	6.8	4.8	8.7
6900-10,499	10.7	16.2	17.5	13.7	14.0	10.5	7.7	12.7
10,500-15,199	21.2	27.7	22.9	31.6	25.7	6.0	17.7	20.6
15,200 +	40.7	32.3	44.7	42.4	49.7	55.7	57.4	47.4

Table 2.7 - Percent New Domestic Car Purchases by Income Class (1973)

Income	Subcompact	Compacts	Intermediate	Standard	Medium	Luxury	Specialty	Misc
0-3499	8.1	10.7	13.6	9.6	11.7	7.9	10.7	7.8
3500-6899	8.3	7.4	8.8	2.0	8.9	12.0	3.3	4.2
6900-10,499	13.7	16.4	13.8	12.5	15.2	2.0	8.8	12.5
10,500-15,199	16.4	18.9	27.6	15.9	19.9	5.1	23.4	21.6
15,200 +	53.5	46.6	36.3	59.8	44.3	22.8	53.6	53.8

Tight Roomy

Table 2.8. Percent New Domestic Car Purchases by Income Class, in Tight and Roomy Size Classes

Income	'Tight'	'Roomy'	Fraction of Owner-Occupied Housing Units with Off-Street Parking
0-6899	20.2	17.0	27
6900-10499	15.1	11.1	56
10500-15199	23.2	15.0	77
15200 +	41.4	56.8	85

Based on this table, we can compute that 67% of the 'tight' vehicles have off-street parking available vs. 71% of the 'roomy' vehicles. This result corroborates the conclusion that vehicle size is indeed correlated with the availability of off-street parking. However, the correlation between the income classes in Table 2.7 and those in Table 4.3 of Appendix A1 is rather uncertain; so we would not put a great deal of faith in the absolute magnitudes. Instead, what we have done is to assume that the availability of off-street parking is uncorrelated with vehicle size, and constructed Table 2.9 on that basis, using Table 2.2 and Table 4.6 of Appendix A1. We have indicated by > (greater than) and < (less than) signs the direction in which the true value lies relative to the computed value.

Table 2.9. Distribution of Cars with Off-Street Parking Available Relative to Usage Patterns and Size Classification (Percentages of 1985 Fleet).

Mission		At Single Family Units	At Multi-Family Units
Usage	Vehicle Size		
Secondary	Tight	<9.6	2.5
	Roomy	>7.5	1.9
Only	Tight	<8.5	5.8
	Roomy	>6.7	4.5
Primary	Tight	<7.8	2.3
	Roomy	>6.1	1.7

2.4.3 Other Considerations - Hybrid Vehicle Market Positioning

From a technical viewpoint, we have demonstrated that a tight 5/6 passenger vehicle could be the basis for the development of a hybrid vehicle or a traditional 6 passenger roomy car could more easily be a base for such development (see Section 2.5.2). The non-technical considerations that would guide an automotive manufacturer are important to understand and consider in the final selection process. These factors, their import, and the direction in which they could guide a basic product planning decision are discussed below. Where additional data can be obtained to deal more effectively with these issues, we plan to obtain such data and include it as part of our tradeoff studies.

Price Sensitivity. The cost of offering a hybrid propulsion system in cars does not follow the normal pattern of bigger = costlier. In the case of a choice between a tight 5/6 passenger car and a roomy

6 passenger, the Δ cost of a hybrid system could be less for the roomy car for two reasons: 1) the tight 5/6 passenger car would not be able to handle the added weight of the hybrid propulsion system without beefing up suspension and body structure, thus, creating unique costly low volume components; and 2) the engine in the tight 5/6 passenger car is a relatively inexpensive 4 cylinder engine while the roomy 6 passenger car is equipped with a V-8 engine. The cost offset to the hybrid engine is, therefore, much greater in the case of the roomy V-8. For purposes of developing this issue further, if we were to use the purchase price = 2 x manufacturing cost formula, the following might apply:

	Tight 5/6 Passenger Fairmont	Roomy 6 Passenger LTD	Remarks
Base Retail Price ca.	$ 5,000	$ 7,000	
Typical Options	1,500	1,000	Auto trans, power steering, & brakes std LTD
Typical Retail Price	$ 6,500	$ 8,000	
Hybrid Price = 2 x cost	3,000	2,500	
Typical Retail Price - Hybrid	$ 9,500	$10,500	
Hybrid % over Typical Base Vehicle	46%	31%	
Roomy 6 Passenger Typical Retail (over) Tight 5/6 Passenger		$ 1,500 23%	
Roomy 6 Passenger Hybrid Retail (over) Tight 5/6 Passenger		$ 1,000 11%	

To assess the relative sales potential of the two different sized hybrids, the issue comes down to an understanding of the price sensitivity of the two market segments involved in the pricing of a hybrid. It is certain that a $10,500 price for a roomy six passenger car would be far less of a problem than a $9,500 price for the smaller hybrid. The issue is, what is the price sensitivity in the two classes under consideration. We intend to have this answer as a part of our tradeoff study report.

Pricing Policies of Manufacturers For Fuel Efficient Vehicles vis-a-vis Conventional Vehicles. In the 1985 time frame, manufacturers must take drastic actions in order to meet mandated CAFE levels. The relatively easy gains brought about through downsizing and performance reduction will have run the gamut by the 1980-81 time period and will only just meet the not too stringent standards in effect for those years.

Further gains must be achieved by dieselization of a major share of the fleet, more massive material substitution at cost penalties, and a change in mix toward smaller, less profitable cars. Of these options, only dieselization of the fleet represents an approach that will not deteriorate profits. With the EPA after unregulated diesel emissions and with stringent controls of particulate levels being proposed by 1981-1983, it is very possible that the diesels that meet regulated particulate levels cease to offer the manufacturers an attractive alternative for 1985. Other alternate powerplants, such as the Stirling engine and the Brayton engine, are no longer contenders for the 1985-90 time frame. The Ford decision

to withdraw from the Stirling program and the poor fuel economy performance of the Brayton engine support this conclusion. It is possible that these engines may become viable over the long term (1990-2000), but are not considerations for 1985. From our preliminary data, a hybrid vehicle is one of the best prospects for the 1985-90 time frame as a means of achieving CAFE requirements. If available in the roomy, but normally less fuel efficient conventional vehicles in a manufacturer's product line, it could significantly improve the fuel economy of the larger cars and increase the CAFE level by the greatest amount (as compared to introducing hybrids in vehicles such as the Fairmont/Nova, which will already be fuel efficient in 1985). The pricing policy of the manufacturer can well determine the volume potential of the hybrid; and, thus, there should be no incentive to make more profits on the hybrid version of a large car. We would, thus, expect that the retail price increase for a large hybrid would be at a level where there is a cost pass-through that recovers the incremental manufacturing cost and the amortization of additional investment in tooling and manufacturing equipment. This would be far below the 2.0 x manufacturing cost guideline provided by JPL.

If a hybrid were to be offered in a smaller, more fuel efficient vehicle that offers a smaller CAFE improvement, it is likely that the manufacturer may elect to price the vehicle so as to increase the profit return of the smaller, less profitable car line.

Impact of Energy Pricing and Consumer Perceptions of Breakdown Operating Costs. Rapidly rising petroleum prices as set forth in

the JPL Assumptions and Guidelines and as defined for sensitivity study, combined with electricity cost assumptions which are likely to rise at more modest levels, are approaching price levels at which a hybrid vehicle becomes a cost effective purchase decision.

We believe the general public is far more aware of the cost of gasoline than of the cost of a kilowatt hour of electricity; and, thus, the dramatic improvement in petroleum fuel consumption combined with the rapidly rising petroleum prices would make a well designed hybrid, priced reasonably, a potential sales success.

Even those new car buyers such as fleets that pay close attention to operating costs could accept a reasonable penalty by considering what may happen to petroleum prices and availability in the future. What, after all, comes after Iran?

2.5 Reference ICE Conventional Vehicle

2.5.1 Reference Vehicles in 'Tight' & 'Roomy' Size Classes

As indicated in the previous discussion, there is no basis for associating different types or sizes of vehicles with the different usage patterns; rather, the different sizes are associated with different perceived requirements of the drivers. Consequently, the approach taken with regard to the definition of reference vehicles was to 'construct' two: one representing the 'tight' size class, the other, the 'roomy' class. These can then be used as bases for comparison with hybrids for any of the usage patterns.

The starting point in constructing these vehicles was to select two recent 'clean sheet of paper' designs which satisfy the minimum vehicle requirements R1–R10 and which are as close as possible

to the JPL projections for 1985. In Table 2.10, the JPL new car fleet inertia weight data for 1976 and projections for 1985 are used to obtain a hypothetical breakdown of curb mass for the current (1979) model year, assuming a linear change within each class over the 1976-1985 period.

Table 2.10 1979 New Car Weight

	IW (lbs)	Curb Mass (kg)
Small	2160	845
Subcompact	2470	986
Compact	3050	1250
Full size	4000	1682
Large	4800	2045

Table 2.11 shows the minimum curb masses of representative 1979 model 4-door cars from each of the three major manufacturers, along with their seating capacities, their size classifications based on Table 2.10, and their size classifications based on interior and luggage compartment volume (EPA).

Table 2.11 - Mass, Capacity, and Size Classification of Representative American 4-Door Cars

Manufacturer	Car Line	Min. Curb Mass for 4-Door (kg)	Designated Seating Capacity (front/rear)	Size Classification: Weight (JPL)	Size Classification: Volume (EPA)
Chrysler	Dodge Omni	996	2/2	Subcompact	Subcompact
	" Aspen	1454	3/3	Compact	Compact
	" Diplomat	1555	3/3	Full-size	Mid-size
	" St. Regis	1667	3/3	Full-size	Large
Ford	Fairmont	1254	2/3	Compact	Mid-size
	Granada	1462	2/3	Compact	Compact
	Ford (LTD)	1627	3/3	Full-size	Large
	LTD II	1798	3/3	Full-size	Mid-size
	Lincoln Versailles	1737	2/3	Full-size	Compact
	Lincoln	2199	3/3	Large	Large
GMC	Buick Skyhawk/ Skylark	1486	3/3	Full-size	Compact
	Buick Century	1430	3/3	Compact	Mid-size
	" LeSabre	1633	3/3	Full-size	Large
	" Electra	1804	3/3	Full-size	Large
	Chevrolet-				
	Chevette	957	2/2	Subcompact	Subcompact
	Nova	1500	3/3	Compact	Compact
	Malibu	1399	3/3	Compact	Mid-size
	Impala	1634	3/3	Full-size	Large

In Table 2.12, the JPL projections for the 1985 new car fleet are used to estimate the average inertia weight and curb mass of the two size classes we have chosen ('tight' and 'roomy'), under the previously discussed assumptions concerning the relationship between these classes and the JPL categories of compact, full size, and large.

Table 2.12 – 1985 Projected Curb Mass & Fuel Economy for Tight and Roomy Vehicles

JPL Size Class	Inertia Wt. (lbs)	Vehicle Class	Avg. Inertia Wt. (lbs)	Curb Mass (kg)
Compact	2650			
		Tight	2890	1177
Full Size	3375			
		Roomy	3712	1551
Large	4050			

Reviewing Table 2.11, it is clear that the 1979 model year car which comes closest to representing what we have defined as a 'tight' 1985 car is the Ford Fairmont. The curb mass is very close, it has a 'midsize' volume rating, which means that its interior volume is larger than other vehicles with a 'compact' volume rating which weigh more, such as the Dodge Aspen, Ford Granada, Lincoln Versailles, Buick Skyhawk/Skylark, and Chevrolet Nova. (Note that, at this writing, data on the downsized 1979½ Nova was not available; otherwise, it too might be a candidate.)

Vehicles which are close to the 1985 'roomy' class in terms of curb weight and which have a 'large' volume rating include the Dodge St. Regis, Ford LTD, Buick LeSabre, and Chevrolet Impala. Of these, the LTD is (marginally) the lightest and the logical choice.

The weight differentials between the Fairmont and LTD, and corresponding projected 1985 'tight' and 'roomy' vehicles are, respectively 77 kg and 76 kg; it is entirely reasonable to expect that weight reductions of this order could be attained over the intervening years. The space/weight efficiency of these two cars relative to their contemporaries and predecessors in the Ford line is illustrated in more detail in Table 2.13.

The logical approach, then, in constructing 1985 reference vehicles in the two size classes would be to start with the 1979 Fairmont and LTD and project the evolutionary changes that might occur in these vehicles between now and 1985. In making these projections, we have used the work which South Coast Technology did in 1977-1978 on a NHTSA contract as a basis.(4)

In projecting 1985 technology to these two vehicles, we made the following assumptions:

- Drag coefficient could be reduced from the current value of approximately .54 for the Fairmont (assumed similar for the LTD) down to .40.
- Rolling resistance could be reduced from a current value of approximately .015 down to .010. (Rolling resistance includes tires, wheel bearings, and seal drag.)
- The automatic transmission torque converter would lock up on the top two gears.
- A 4% improvement in average engine efficiency from 1978 to 1985 could be obtained.

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(4) Augmentation of Research and Analysis Capabilities for Timely Support of Automotive Fuel Economy Studies. Draft Final Report for Selected Task Areas, NHTSA Contract No. DOT-HS-01790, South Coast Technology, Inc., March, 1978.

Table 2.13 - Size and Weight Comparisons in Ford Line

	(Tight)			(Roomy)	
	LTD II	Granada	Fairmont	LTD (1978)	LTD (1979)
Front Compartment					
Head room (cm) h_1	95.0	96.5	97.3	96.3	96.5
Leg room l_1	107.4	103.4	106.2	106.4	106.9
Shoulder room s_1	148.8	141.7	144.0	155.7	156.7
Rear Compartment					
Head h_2	91.9	92.7	95.2	94.0	95.0
Leg l_2	84.1	86.4	89.9	96.5	102.9
Shoulder s_2	144.5	138.2	144.0	156.0	156.7
Room Index *	556	531	560	613	629
Luggage Volume (m^3)	.45	.44	.48	.64	.66
Curb Mass (kg) (min)	1798	1462	1254	2001	1627

$$* = \frac{(h_1 + l_1)\, s_1 + (h_2 + l_2)\, s_2}{100}$$

Some comments are in order regarding these assumptions. First, with respect to air drag, we see no evidence in any recent, well documented results from full scale wind tunnel testing that values significantly less than .4 are likely to be obtained on sedan type vehicles. Even the Porsche 924, which is a sports car designed from the ground up, with the aid of wind tunnel testing, to be aerodynamically efficient, has a reported drag coefficient of .36[5]—not far from .4. To quote one of the conclusions from (1), "The ultimate C_D for a sedan is probably about .31; however, this involves design characteristics which are not acceptable now, have not been in the past, and will probably not be so in the future."

With respect to rolling resistance, we feel that .015 is a good number for current radial tires at normal inflation pressures; for example, it is consistent with published VW data[6] on the road load for its Rabbit, and is also consistent with our own test results on our electric conversion of the Rabbit (which uses steel belted radials). Projections of rolling resistance on the order of .006-.008 are sometimes seen; however, on a real car, on a real road, with the drag of seals, wheel bearings, brake discs, and so forth, taken into account, a value of .010 is a more realistic assessment of what is attainable by 1985 (using, for example, Goodyear elliptics or high pressure belted radials).

The assumption of a lockup torque converter requires no discussion; they already are in production by one manufacturer.

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(5) H. E. Burst and R. Srock, "The Porsche 924 Body - Main Development Objectives," Porsche AG, SAE Paper No. 770311, Feb., 1977.

(6) P. Hofbauer and K. Sator, "A Diesel for a Subcompact Car," Volkswagenwerk AG, SAE Paper No. 770113, March, 1977.

The assumption of a 4% improvement in engine efficiency is, again, based on the SCT work.(4) This gain is the result of a projected net improvement of 12% due to the factors indicated in Table 2.14 (from (4)), combined with an 8% loss in meeting 1985 emission standards (.41 HC, 3.4 CO, 1.0 NOx). In short, efficiency of a typical engine in 1985 is not likely to be much different than in 1978 due to the need to meet tighter emissions standards.

Table 2.14 - Individual Gains and Losses in Power Plant. (1978, 1.5 HC, 15 CO, 2.0 NOx to 1983-85, 41 HC, 3.4 CO, 1.0 NOx)

	Gain
Improved carburetion or fuel injection for better fuel atomization and engine fuel distribution.	2%
Further optimization of tradeoffs between EGR, fuel flow, spark advance, and other engine operating variables in conjunction with computer controlled calibration systems.	6%
Improved EFE, early fuel evaporation systems for improved driveability.	0
Improved combustion chamber design for lower emissions and lower octane requirement increasing compression ratio including the availability of higher octane fuel.	2%
Redesigned basic valve timing for improved fuel efficiency at idle and low end part throttle.	1%
Reduced internal engine friction by design.	1%
TOTAL	12%
Loss in meeting .41 HC, 3.4 CO, 1.0 NOx emission standards.	-8%
NET GAIN	4%

2.5.2 Accommodation and Payload for Reference Vehicles

Table 2.15 provides a summary of the accommodations and nominal payload of the Fairmont and LTD relative to the minimum vehicle requirements specified by JPL in the work statement.

Table 2.15 - Accommodations & Payload of Fairmont and LTD

	Fairmont	LTD	Min. Requirements
Seating capacity	5 (1)	6	5
Luggage volume (m^3)	.48	.66	0.5
Nominal payload (kg) (2)	500	720	520

Notes: (1) Fairmont's 5 passenger capacity is a consequence of the number of seat belts provided, not of space limitations.

(2) Computed as the difference between max. GVW and basic car with power disc brakes, air conditioning, automatic transmission, and radio, and in the case of the LTD, a luxury interior group.

Obviously, the Fairmont is marginal relative to the minimum luggage volume and payload requirements; and upgrading would be required in these areas for the 1985 version to qualify as a reference vehicle. (It should also be noted that the minimum payload requirement of 520 kg is unusually severe for a 'tight' vehicle. A more normal payload for a car such as the Fairmont is in the 400 to 450 kg range.) The LTD, on the other hand, has a wide margin relatively to the luggage volume and payload requirements, which brings up another point. Historically, a production volume of 100,000 units/year is not an economical proposition for a unique car (as American Motors will attest to), except for high priced vehicles with a

special and limited market which limits their potential impact on petroleum consumption.

Consequently, if a hybrid vehicle were to be put into production, it would undoubtedly share basic components with a parallel line of conventionally powered vehicles. Thus, if Ford Motor Co. were to plan production of a hybrid, the LTD would be a better candidate as a starting point than the Fairmont would since it does have superior payload and capacity; and consequently, the modifications required to upgrade it to accept the additional weight and volume associated with a battery pack would be minor compared to the Fairmont, which might have to be totally re-engineered.

2.5.3 Performance of Reference Vehicles

The performance of the Fairmont based reference vehicles was estimated using the vehicle simulation program VMODEL, which SCT has had operational since 1977; that of the LTD based reference vehicle was estimated by adjusting the Fairmont results to take into account the higher power-to-weight ratio (.052 kw/kg for the LTD vs. .046 kw/kg for the Fairmont). Table 2.16 shows a comparison of these results with the JPL-specified minimum requirements.

Table 2.16 – Performance of Reference Vehicles vs. Minimum Requirements

	Fairmont-based	LTD-based	Min. Requirements
Accel. 0-50 km/hr(sec)	5.2	4.6	6
0-90 " "	14.9	13.5	15
40-90 " "	11.1	10.0	12
Gradeability 3%	>115 kph	>115 kph	90 kph/1km
8%	99 kph	110 kph	50 kph/.3km
15%	66 kph	74 kph	25 kph/.2km

2.5.4 Fuel Consumption of Reference Vehicles

The on-road fuel consumption of the reference vehicles was estimated by two methods. The first, and simpler, method utilized the projections of 1985 fuel economy given in Table C-1 of the Assumptions and Guidelines. Using the formula

(1) FE(on-road mph) = .71(EPA composite mpg) + 2.83,

the on-road fuel economy was estimated for the compact, full size, and large size classes. Then, using the new car fleet mix projected for 1985 together with our assumption that our 'tight' car represents the compacts and the bottom half of the full size class, and the 'roomy' car the rest of the full size class and the large class, the on-road economies of the two reference vehicles were computed as the appropriate weighted harmonic averages. The results are summarized in Table 2.17.

Table 2.17 - Fuel Economy of Reference Vehicles (Estimate 1)

Class	IW (lbs)	On-road F.E. (mpg)	Ref. Vehicle	IW (lbs)	On-road F.E. (mpg)
Compact	2650	25.6	Tight	2890	23.7
Full Size	3375	20.6	Roomy	3712	19.0
Large	4050	17.7			

The second method of estimation involved considerably more detail regarding the projected characteristics of engine and vehicle in 1985. The process was gone through for the Fairmont-based reference vehicle; the same relative improvement was then assumed for the LTD-based reference vehicle. The process involved the following.

First of all, the only published engine mapping data available on a close relative of the 1978-79 Fairmont 4-cylinder engine is on this same basic engine in 1975 form(7), which was used in the Pinto at the time, the Fairmont not being in production then. The first step was to use this data, in conjunction with data on the 1975 Pinto, in the VMODEL simulation, to establish a correlation between fuel economy estimates made by the simulation and those made as a result of EPA tests on the actual vehicle. The results are shown in Table 2.18.

Table 2.18 - Comparison Between EPA Test and VMODEL Simulation for 1975 Pinto with Automatic Transmission

Cycle	EPA Test	Simulation	Ratio, $\frac{\text{Simulation}}{\text{EPA Test}}$
Urban	18 mpg	19.7 mpg	1.094
Highway	26	26.7	1.027
Composite	20.9	22.3	1.067

The differences between the simulation results and EPA test results result from:

- Possible errors in estimating drag coefficient, rolling resistance, and drivetrain efficiencies.
- Individual engine variations.
- Cold start on the urban cycle, which is not simulated in the computer model.

(7) W. F. Marshall & K. R. Stamper, "Fuel Consumption, Emissions, and Power Characteristics of the 1975 Ford 140 CID Automotive Engine," U. S. Energy Research & Development Administration, Bartleville Energy Research Center, November, 1976.

In view of the fact that the highway cycle results are much closer than the urban cycle results, the last of the above factors is probably the most significant.

Table 2.19, thus, gives us a set of correction factors to get from simulation results to estimates of the EPA urban and highway mileage. The next step was to run a simulation of the '75 engine in the '85 reference vehicle to determine what effect the vehicle changes (lower drag coefficient and rolling resistance, and use of a lockup torque convertor) would have on fuel economy, and then apply the correction factors determined from Table 2.18. The results are shown in Table 2.19.

Table 2.19 – Estimated Fuel Economy of 1975 140 CID Engine in 1985 Fairmont-based Reference Vehicle

Cycle	Economy from Simulation	Economy on EPA Test Procedure
Urban	20.8	19.0
Highway	32.5	31.6
Composite	24.8	23.2

The next step involves correcting these results to take into account engine changes from 1975 to 1985. From 1975 to 1978, the composite cycle fuel economy reported for the Pinto went from 20.9 to 26 mph, for an improvement of 24%. The engine changes which accomplished this included the following:

- Increase in compression ratio from 8/4 to 9.0.
- Increase in maximum centrifugal advance from 14° at 4500 RPM to 25° @ 5000 RPM.

- Decrease in the RPM at which centrifugal advance starts from 1350 to 1020 RPM.
- Increase in maximum vacuum advance from $5\frac{1}{2}^{\circ}$ @ 7 in. Hg, to 24° @ 12.4 in. Hg.
- Decrease in vacuum at which vacuum advance starts from 4 in. Hg to 2 in. Hg.

Our own estimate is that these changes (of which the revised advance curves are most significant) would result in an improvement in full throttle bsfc on the order of 15%. The improvement at part throttle (high vacuum) would be more, so the increase in overall efficiency of 24%, obtained from the composite cycle fuel economy, is not unreasonable. As discussed previously, we are estimating the improvement between now and 1985 at about 4%. If we apply these factors to the numbers, we get results shown in Table 2.20.

Table 2.20 - Estimated Fuel Economy of 1985 Fairmont-based Reference Vehicle (EPA Test Procedure)

Cycle	Fuel Economy
Urban	24.5
Highway	40.8
Composite	29.9

If we now apply formula (1) relating on-road to EPA composite fuel economy, we arrive at a figure of 24 mpg for on-road fuel economy for the Fairmont-based reference vehicle, very close to the 23.7 mpg obtained from the JPL projection.

For the LTD, a similar analysis was not possible since detailed

engine data was not available to us; consequently, an estimate for its on-road fuel economy was obtained in the following manner.

First, the EPA test on the urban cycle gives a number of 14 mpg for the '79 LTD; EPA no longer publishes highway cycle results, but a reasonable estimate would be 20 mpg for a composite cycle economy of 16.2 mpg.

Now, the simulation run with the Fairmont gave an improvement of 15% on composite cycle fuel economy associated with the 1985 vehicle and transmission improvements; this, together with a 4% improvement in engine efficiency yields an estimated composite cycle fuel economy of 19.4 mpg for the 1985 LTD-based reference vehicle. Applying (1) then gives an estimated on-road fuel economy of 16.6 mpg, which is lower than the estimate of 19 mpg obtained from the JPL projections.

To obtain another estimate for the LTD-based reference vehicle, the following was done. Using the hybrid vehicle system level simulation program, HYBRID, which was developed for use in Task 2 (Design Tradeoff Studies), and which will be documented in the report on that task, operation of the Fairmont-based reference vehicle on the driving cycle corresponding to the only driver usage pattern was simulated. The LTD-based reference vehicle was also simulated, using the same general engine characteristics as used for the Fairmont-based vehicle (i.e., at a given ratio of required power to available power, the bsfc was the same for two engines). In this case, a fuel economy 26.5% lower than the Fairmont-based vehicle was obtained. Assuming the same relationship holds for on-road fuel economy, the

LTD-based reference vehicle would get 17.7 mpg vs. the Fairmont-based vehicle's 24 mpg. Again, this is somewhat lower than the 19 mpg obtained from the JPL projections and, as a matter of happenstance, is very close to the average between the previous estimate of 16.6 mpg and the 19 mpg figure.

As a result of the foregoing considerations, we concluded that the on-road fuel economy for the LTD-based (roomy) reference vehicle would be in the 17-19 mpg range; a representative number was chosen as 18 mpg.

2.5.5 Cost Factors for the Reference Vehicles

Manufacturing Cost for the Reference Vehicles. Manufacturing costs for the two reference vehicles were estimated using the program WANDC, which is described in detail in Appendix A2 of this report. Briefly, the program estimates the weight and manufacturing cost of a hybrid (or conventional) vehicle, given inputs of heat engine power fraction, battery weight fraction, power-to-weight ratio, payload, and an 'irreducible' vehicle carriage weight (i.e., the weight the vehicle would have if all it had to do was carry around passengers and luggage). Internally, the program uses cost and weight vs. power rating relationships for the vehicle carriage (i.e., vehicle less propulsion system) and battery pack. These relationships were derived from data developed by Rath and Strong,[8] updated to reflect the difference in 1975 and 1978 costs (20-25%). The relationships

(8) R. G. Fitzgibbons & L. H. Lindgren, Estimated Weights and Manufacturing Costs of Automobiles, Contract No. DOT-TSC-1067, Task 1 Report, Rath & Strong, Inc., 1975.

are used, together with a weight propagation factor for the vehicle carriage, to derive an overall weight and cost for the vehicle, as well as costs and weights for the propulsion system components. A weight propagation factor of .2 was used; i.e., for every kilogram added in propulsion system weight or payload, an additional .2 kilogram is added to the vehicle carriage in additional structure, heavier duty suspension and brakes, and so forth.

Computed in this fashion, the manufacturing cost of the Fairmont was estimated at $2,613, and the LTD at $3,528. The computed curb masses were 1308 kg and 1724 kg, respectively. These numbers are in reasonable agreement with the approximate discounted retail prices of these two cars of about $5,000 and $7,000, and curb masses of about 1300 and 1700 kg when equipped with a minimum option list, including air conditioning.

To the above manufacturing costs must be added the cost differential associated with the engine and other improvements projected for the 1985 time frame. These were estimated as follows:

Engine	$290
Lockup Torque Convertor	19
Tires	16
TOTAL	$325

The number for the engine modifications was developed by SCT in the previously mentioned NHTSA contract.[4] The cost is largely associated with fuel system controls and sensors, include a microprocessor, and is thus relatively independent of the engine size. The cost differential for the addition of a lockup torque convertor

was provided by C. E. Burke Engineering Services, SCT's heat engine/transmission subcontractor. Again, there is no significant difference in the cost increments involved in adding this device to the Fairmont and LTD transmissions. The cost increment for low rolling resistance tires is an educated guess, based on current cost differences between various tire types.

Consequently, to obtain manufacturing cost estimates for the 1985 Fairmont- and LTD-based reference vehicles, $325 was added to the current values estimated for the Fairmont and LTD by the program WANDC. The results are $2,940 for the Fairmont-based vehicle, and $3,850 for the LTD-based vehicle.

Life Cycle Cost for the Reference Vehicle. Life cycle costs for the reference vehicles were estimated using the program LYFECC, which is described in detail in Appendix A3 of this report. This program utilizes the assumptions specified by JPL in the Assumptions and Guidelines, and computes life cycle cost over a 10-year period. Table C-3 of the Assumptions and Guidelines was adjusted so that the overall average annual travel per vehicle agrees with the JPL projection of 19645 km for the year 1990 (the midpoint of the 10-year period starting in 1985), and this data was used in the life cycle cost program to define the distance travelled in each of the 10 years. As a result of the high VMT shown in Table C-3 for the first four years of a vehicle's life, the total mileage accumulated during the 10 years over which the life cycle cost is computed is high: approximately 220,000 km, or 137,000 mi, instead of the 100,000 miles normally assumed. As a consequence, the life cycle costs computed tend

to be on the low side (since the initial investment is spread out over more miles), with a larger fraction of the total costs associated with operating costs and maintenance and repair than might normally be anticipated. However, the methodology is consistent with the Assumptions and Guidelines provided by JPL and is representative of a trend toward increased vehicle utilization.

Fuel consumption throughout was assumed to be represented by the fuel consumption on the 'only' driver composite driving cycle. Actually, the usage patterns during the first three years of ownership are probably more closely represented by the 'primary' driver pattern. However, the fuel consumption difference between these driving patterns is less than 10%, as we shall discuss in the next section. Consequently, the distinction is hardly worth making. With this methodology, the life cycle cost of the Fairmont-based reference vehicle was estimated to be 7.2¢/km, and that of the LTD-based vehicle, 9.4¢/km.

2.6 Fuel Consumption of Reference Vehicle Fleet

To ensure consistency between the fuel consumption estimates to be made for hybrid vehicles in Task 2 and those made for the reference vehicles, the hybrid vehicle system level simulation was used to estimate the fuel consumption of the reference vehicles for each of the three usage patterns, using the composite driving cycle described in Section 7 of Appendix A1. The on-road fuel economy estimates and corresponding annual fuel consumption per vehicle are given in Table 2.21.

Table 2.21 - Fuel Economy of Reference Vehicle

Mission: Usage Pattern	Mission: Annual Travel (1985)	Vehicle Size	FE (mpg)	Annual Fuel Consumption (gals.)
Secondary Driver	11300 km	Tight	22	319
		Roomy	15	468
Only Driver	19100 km	Tight	24	495
		Roomy	18	695
Primary Driver	29900 km	Tight	26	715
		Roomy	19	978

Going back to the percentages shown in Table 2.2, we find that, if all the vehicles in these size classes in the 1985 fleet were replaced by these two reference vehicles, the fuel consumed would be given by the numbers shown in Table 2.22 (assuming a total fleet size of 113 x 10^6 vehicles).

Table 2.22 - Distribution of Fuel Consumed by Reference Vehicles in 1985 Fleet

Mission		Fuel Consumption (Gal. x 10^{-6})		
Usage	Vehicle Size	Cars at Single Family Units	Multi-Family Units	TOTAL
Secondary	Tight	4430	970	5,400
	Roomy	5080	1110	6,190
Only	Tight	6260	3470	9,730
	Roomy	6550	3570	10,120
Primary	Tight	8080	2020	10,100
	Roomy	8620	2100	10,720

Thus, we come to the conclusion that more fuel will probably be consumed in the 1985 fleet by cars of the 'roomy' class than by

those of the 'tight' class, despite the fact that the roomy car class is a smaller segment of the fleet.

When we consider the segment of the fleet which could be replaced by hybrids in the 'tight' and 'roomy' categories, we get the results shown in Table 2.23, under the assumption that the availability of off-street parking for battery recharge is uniformly distributed relative to the two size classes, as was done in the construction of Table 2.9 in Section 2.4.2. As before, the $<$ and $>$ signs have been added to indicate that this assumption is not true, at least in the case of cars located at single family dwellings, and to indicate the fact that there is a higher probability that a 'roomy' class vehicle could be replaced by a hybrid than a 'tight' class vehicle, from the standpoint of electrical service for battery recharge being available.

Table 2.23 – Distribution of Fuel Consumed by Reference Vehicles in 1985 Fleet with Off-Street Parking

Mission		Fuel Consumption (Gal. x 10^{-6})		
Usage	Vehicle Size	Cars at Single Family Units	Multi-Family Units	TOTAL
Secondary	Tight	<3460	900	<4360
	Roomy	>3970	1000	>4970
Only	Tight	<4750	3240	<7990
	Roomy	>4990	3350	>8340
Primary	Tight	<6300	1860	<8160
	Roomy	>6740	1880	>8620
		Total 'Tight'		20510
		Total 'Roomy'		21930

2.7 Selection of Mission/Reference Vehicle

In previous sections, the 'taxi' mission was not discussed in any detail for the following reason: As can be seen from the data in Section 6 of Appendix A1, it accounts for a total of about 2% of the total passenger car vehicle miles travelled in the country. Consequently, replacement of this fleet by hybrids will not, under any circumstances, have a very large effect on petroleum consumption. Moreover, as indicated in Table 6.1 of Appendix A1, most taxis are used in a multi-shift operation in which there is not time available for battery recharge; so, most of their energy consumption would have to come from petroleum. For these reasons, the taxi mission can be dropped from consideration.

With respect to other private car missions, the only factor which is truly relevant to the design of the vehicle is the size classification – tight or roomy. A vehicle cannot really be designed 'for' a primary driver, or an only driver, or a secondary driver, to the exclusion of the other categories because that is not how vehicles spend their lives. In general, the usage patterns tend more toward that of the primary driver during their first few years and toward the secondary driver during their declining years.

The data from Table 2.23 indicates that the potential for petroleum conservation by hybrids is very nearly the same in the two classes of vehicles, with perhaps the higher potential being associated with the 'roomy' class. As noted, the numbers in this table do not take into account the following:

- The 'roomy' vehicle owner is more likely to have off-street parking for recharging batteries.
- He is more likely to accept the retail price differential of the hybrid.
- The amount of re-engineering and modification of the 'roomy' vehicle structure and running gear to accept a hybrid propulsion system is likely to be much less than that required for a 'tight' vehicle; thus, a 'roomy' hybrid vehicle is likely to be an economically more viable vehicle to produce than a 'tight' vehicle.

All these factors drive the balance in the direction of the 'roomy' vehicle; what Table 2.23 indicates to be a near-wash situation becomes one which clearly is favorable to the 'roomy' hybrid.

Consequently, we have selected the 'roomy' class for the vehicle size aspect of the mission which offers the greatest potential for petroleum conservation, and the LTD-based reference vehicle to represent a comparable IC engined vehicle.

An analogous situation to the one which led to the selection of the 'roomy' class vehicle for the near term hybrid has already occurred in the real world; that is, General Motors introduction of diesels in its Cadillac and Oldsmobile lines to meet legislated CAFE requirements. It is illustrative of the fact that a manufacturer will put the greatest emphasis on improving the fuel economy of his least fuel efficient lines of vehicles, particularly if they are lines whose market share it would be desirable to maintain from the profitability standpoint. This is a consequence of the use of

harmonic averaging to determine a manufacturer's CAFE. As an example, consider a manufacturer with two lines of vehicles, of equal production volumes, one of which averages 15 mpg and the other 30 mpg for a harmonic mean of 20 mpg. If the fuel economy of the 30 mpg car is improved by 50% to 45 mpg, the harmonic mean fuel economy improves to only 22.5 mpg; however, if the 50% improvement goes to the 15 mpg car, the mean fuel economy goes to 25.7 mpg. Manufacturers clearly recognize this and would, therefore, gain the most from this program if the hybrid vehicle design we undertake is in that 'roomy' car category.

As far as the usage pattern portion of the mission definition is concerned, a vehicle is likely to experience all three during its lifetime. However, the 'only' driver usage pattern can be used as an overall average. For example, if the total fuel consumption figures shown in Table 2.23 are recomputed using the 'only' driver usage pattern throughout, they change by only 3.5% for the 'roomy' vehicle and less than 1% for the 'tight' vehicle—certainly a smaller variation than the tolerances on the numbers for availability of recharge facilities and other critical areas of this analysis. Consequently, for the purposes of vehicle and propulsion system design, and estimating fuel and energy consumption, it suffices to work with the 'only' driver travel distribution.

2.8 Mission Related Vehicle Characteristics

2.8.1 Capacity (Passengers and Cargo)

Since the mission represented by the 'only' driver travel distribution and owner-perceived requirements for a roomy, six

passenger automobile was selected, a six passenger capacity is an obvious mission-related characteristic. In this section, we shall present some more detail on the definition of passenger and cargo capacity.

Our basic premise in establishing these requirements is that the hybrid vehicle must offer to the buyer an equivalent vehicle from a utilitarian standpoint if it is to be perceived and accepted as a viable alternative. This is particularly true with respect to vehicle size. If a hybrid were to force a buyer to give up passenger or cargo capacity, the buyer could do this far more cost effectively by buying a smaller car with its improved level of fuel economy.

A six passenger vehicle should, as a minimum, accommodate two (2) 95 percentile males and four (4) 50 percentile males. These proposed requirements meet the vehicle minimum requirement of the statement of work. However, since many compact vehicles are classified as six passenger vehicles (but cannot be considered comfortable for six passengers), it is necessary to further quantify the interior room available. Consequently, using the LTD as being representative of the amount of interior room which should be provided in a 'roomy' six passenger car, we concluded that the hybrid vehicle should meet or exceed the interior dimensions shown in Table 2.24.

Table 2.24 - Minimum Interior Dimensions for 'Roomy' Class Hybrid

	Front Compartment	Rear Compartment
Head room (cm)	96	94
Shoulder room (cm)	155	155
Leg room (cm)	106	96

Cargo Capacity. Following the principle of not requiring a hybrid vehicle buyer to give up attributes he could find in a conventional propulsion system vehicle, our objective is to establish an achievable and adequate capacity that recognizes the space lost in the vehicle to accommodate batteries and/or other portions of the hybrid propulsion system.

For the 6 passenger hybrid vehicle, we would recommend a luggage compartment capacity equivalent to the space available in a typical Ford LTD (.66 m^3) or Chevrolet Impala (.57 m^3). A compromise between these two vehicles would seem reasonable; and for this reason, we have selected 0.6 m^3 as the recommended capacity.

Payload Capacity. The payload capacity designated by a manufacturer becomes crucial in a hybrid vehicle since its basic propulsion system results in a curb weight significantly above others in its size/passenger accommodation class. Whatever payload is selected must be accommodated by the wheels and tires used and other chassis and structural items; and, in addition, there is an implied warranty by the manufacturer that the vehicle will perform satisfactorily at the maximum payload.

We have reviewed the gross vehicle weight vs. curb weight for full size, six passenger cars, and have determined payload capability based on the number and weight of passengers provided for, and for the recommended manufacturers luggage compartment weight allowance.

	Six Passenger
Passenger Accommodation (kg)	480
Max Trunk Cargo Load (kg)	50
Total Payload	530

This is very close to the minimum requirement of 520 kg specified by JPL; consequently, we set the payload requirement at the minimum requirement.

2.8.2 Range, Speed, Acceleration, and Gradeability

Obviously, the designated mission can be performed by vehicles with a wide range of performance capabilities; and, just as obviously, the buyer of a car has some perception of a minimum performance level which is acceptable in a car of the class he is buying. As indicated in Table 2.16 in Section 2.5.3, the performance of the LTD-based reference vehicle is on the order of 10% better than the JPL minimum requirement of 0-90 kph in 15 sec, which is a measure close to the traditional 0-60 mph time. This is close enough so that the JPL minimum requirement is used. Further discussion of acceleration and gradeability requirements, and the relationship between them and safety, is given in Section 2.8 on the development of performance specifications.

With respect to range, we have already stated as a design criterion that the operating range should not be limited by battery state of charge. Range on a tank of fuel should be consistent with normal practice; i.e., at least 400 km in highway driving.

2.8.3 Cost Constraints (Initial and Operating)

The work statement contains two simple and short sentences with respect to cost constraints. We will examine below these constraints and others provided as assumptions and guidelines.

Initial Costs. The work statement provides two important guidelines as follows:

R10.1: Maximum consumer purchase price - competitive with purchase price of reference conventional Internal Combustion Engine (ICE) vehicle.

Purchase Price = 2.0 x manufacturing cost (includes destination, dealer prep and license).

While work on the design tradeoffs is only just beginning, we have an adequate preliminary definition of the key elements that will comprise our propulsion system to have a rough idea of the magnitude of some of the costs involved. It is clear that we will not be able to achieve a maximum consumer purchase price equal to the reference vehicle and could only achieve a 'competitive' price if one were to accept an interpretation of what the word competitive means. We believe that it is realistic to consider that there is a range of prices for each class of car that might be replaced in part by hybrid vehicles. We would plan to investigate such pricing considerations and leave open the issue as to what the maximum consumer purchase price should be and could be for a given hybrid vehicle. Price sensitivity, energy prices, and consumer perception of the merits of hybrid vehicles are all factors that we plan to consider. If we were only concerned with building two or three hybrid test vehicles for JPL, these factors could be ignored. That is not our assignment, and we accept the challenge of designing a producible hybrid vehicle that will result in the greatest amount of total petroleum savings; and, thus, the vehicle and its place in the marketplace are of major import to us. We do not believe it appropriate to attempt to offset a major part of the hybrid propulsion system

costs by design actions to the rest of the car to cheapen it. Such actions, if possible, should also apply to the reference vehicle and, therefore, do not solve a cost problem.

Recommendation: Leave the existing work statement requirement unchanged as an objective and accept the fact that contractors will have to deal with the issue in submitting the Design Tradeoff Studies Report. JPL may wish to consider a memo on this subject to the four contractors or could let the matter rest and review the data that will be included in the Task 2 Design Tradeoff Studies.

The issue of the purchase price being a simple mathematical relationship to manufacturing cost is an area that we take exception to. We can understand the reasoning for having each contractor evaluate and submit data on the same ground rules. We would be prepared to do this as one reference point. Our concern is that the guideline is unrealistic for each hybrid vehicle approach and that it could result in an excessive price increment for a hybrid which would distort initial price, impact total volume sales potential, and result in unrealistic consumer acquisition and operating costs. Automotive pricing and pricing policy within each manufacturer varies widely. Until recently, there were primarily two types of pricing used by the auto industry - cost and image.[9] A third and important pricing option relating to achieving compliance with CAFE requirements is now developing, an option we shall identify as CAFE;

(9) "Automobile Marketing Strategies, Pricing, and Product Planning." Final report for U. S. Department of Transportation, TSC Contract No. DOT-TS-13632, ASL Engineering, Inc. (Principal Author: H. M. Siegel), June, 1977.

and this third option must be evaluated in the pricing of hybrid vehicles.

Cost pricing is used by the industry in two instances. In the process of designing new product offerings, the manufacturer will select a target price for a new vehicle as one of the initial constraints. Cost targets are then set that will enable the manufacturer to achieve an acceptable profit level for that class and type of car. Before a project is approved, adequate engineering studies are completed to enable setting a budget for the manufacturing cost and tooling for each detailed component that comprises a part of the car. Final pricing is then accomplished shortly before the car is introduced when actual costs vs. the original targets are known and when current competitive prices are known.

Another application of cost pricing is in determining year to year price adjustments that are made to recover added costs due to economics, regulatory design changes, etc.

In cost pricing, there is no hard and fast rule with respect to the relationship of manufacturing cost to purchase price. If there is any pattern to judge by, it is the usual goal of the manufacturer to achieve a reasonable profit level for each class of car he produces, with nominal profits at the compact/subcompact size cars and with profit margins increasing significantly as full size and large cars are priced. Profit margins for larger and luxury vehicles are 5 to 10 times the profits realized on smaller cars.

It is significant, however, that once a vehicle is priced in relation to competition and to the other cars produced by a given

manufacturer, the impact of cost increases on prices is usually based on cost recovery. When a manufacturer adds more costly emission hardware, he usually accepts a pass-through on cost. When costs for labor and material increase, he usually passes through at cost. A hybrid propulsion system in an already profitable car line could be priced more favorably than a hybrid in a smaller, less profitable car line. There is no formula that we know of that would suggest a purchase price being 2.0 x manufacturing cost, and certainly no formula or pricing policy to support a delta price for a hybrid propulsion system that would be 2.0 x manufacturing costs.

Available data on new car pricing and manufacturing costs is limited, but a report issued in 1977[10] and Table 2.25 below perhaps indicate some more conservative guidelines to hybrid pricing would be in order.

Table 2.25 - Current Cost/Price Structure of an Average U. S. Passenger Automobile*

	1977 Model Year	1978 Model Year
Retail Price, including delivery charges	$ 6720	$ 7130
Delivery Charges	170	190
Retail Price	6550	6940
Wholesale Price	5335	5700
Manufacturer's Costs	4902	5280**
Labor Costs	1656	1800
Material Costs	2074	2190
Other Costs	1172	1240

* With average options.

** Based on sales of 11 million vehicles in model year.

Source: (10) Executive Office of the President, Council on Wage and Price Stability, "Council Analyzes New Automobile Price Increases," November 14, 1977.

Image pricing is in widespread use by the auto industry to exploit the profit potential of their cars by offering derivative models under different names. For years this has enabled GM to achieve major levels of product interchangeability between Cadillac and Chevrolet, and yet, obtain a good market demand for the high priced, high profit Cadillac. Perhaps the best example of image pricing is the Cadillac Seville (Nova base) and the Lincoln Versailles (Granada base). In this instance, Cadillac did a far better design job and has a very successful car - the highest priced Cadillac built on a Chevy Nova base. Ford did not do well, and the design of the Versailles is too much like the Granada/Monarch and sales are dismal. (1978 sales: Seville - 55,721; Versailles - 15,747) Image pricing considerations can play a role in hybrid vehicles, and this issue will be considered in our tradeoff studies.

CAFE pricing is now being used by the auto industry. The first apparent approach is to restructure the prices for optional engines with the hope that a higher price will discourage the sale of the less fuel efficient options. Small domestic cars are not selling well, and part of the problem is the lack of a substantial difference in the prices of the small and large cars. It is likely that this differential will increase in the next few years to enable manufacturers to sell more smaller cars and, thus, achieve their CAFE requirements. It is ironic that the 1973 energy crisis was a major factor in narrowing the gap in small vs. big car prices. At that time, big cars had a temporary setback; and manufacturers chose to recover their economic increases by raising small car prices -

in view of the rapid increases in German and Japanese prices - and leaving large car prices relatively stable.

The availability of the right hybrid vehicle in a manufacturer's fleet can be a most effective means of improving CAFE levels, avoiding potential penalties for non-compliance and offering a commercially acceptable vehicle to the buyers. As discussed in the Hybrid Vehicle Potential Assessment Interim Progress Report of February, 1978, the costs associated with the hybrid can possibly be mitigated by the savings in penalties that might otherwise need to be paid if the CAFE requirement cannot be met.

In summary, all of our review and analysis to date suggests that the guideline that Purchase Price = 2.0 x manufacturing cost is inappropriate as a fixed position. We would suggest one of two alternatives, which are:

a) leave the guideline unchanged but recognize that one or more contractors may choose to present alternative data, or

b) revise the guideline from the words that state the relationship is one which shall be used by all contractors to a more flexible ground rule.

Operating Costs. The objective of achieving life cycle costs that are the same as the average life cycle cost of the reference vehicle is an objective that would be ideal to achieve rapid commercialization of hybrid vehicles.

To date, our analysis cannot be definitive as there are still too many unknowns that must be determined during the tradeoff studies, with the vehicle pricing formula discussed above being one major

factor. Inherently, we do not foresee difficulty in achieving a reasonable level of operating costs for some of the following reasons:

- Heat engine operating costs should decrease; oil and filter change interval could be increased to 10-12,000 miles or one year.
- Electric motor is a reliable component and work could be done to obtain maximum brush life. A one-year service interval should be possible.
- Controller/microprocessor, etc. Reliable design should be achievable.
- Batteries. The selection of the right batteries and control strategy will maximize battery life, which together with the type of battery used, is the key to the operating costs.
- Mechanical and electromechanical systems. These systems that will operate the heat engine and motor and form the interface to the transmission will essentially utilize proven automotive technology and, though complex, should not pose significant areas of repair and maintenance.

Our design tradeoffs will consider these and other factors, and our Phase II design approach will be oriented toward using reliability engineering disciplines as a design aid to achieve minimal operating costs.

2.S.4 Ambient Conditions, Availability, and Amenities

Ambient Conditions. The vehicle minimum requirements establishes the temperature range over which the vehicle must meet all minimum requirements, a range of $-20^{\circ}C$ to $+40^{\circ}C$ ($-4^{\circ}F$ to $104^{\circ}F$). We believe this is achievable but would plan to achieve a wider temperature range in order to approximate the operating temperature range that a typical U.S. passenger car is designed to ($-20^{\circ}F$ to $+130^{\circ}F$).

Similarly, the self-contained warm up specification which establishes a 10-minute warm up (it should be maximum of 10 minutes rather than minimum of 10 minutes) to reach full performance in the ambient temperature range of $-20^{\circ}C$ to $+40^{\circ}C$ ($-4^{\circ}F$ to $104^{\circ}F$) appears to be achievable and acceptable. Again, data will be obtained on conventional cars; and every effort will be made to cover the same temperature range and time to reach full performance.

The last portion of the requirement that establishes that the vehicle must be operable within one minute in the same ambient temperature range is a reasonable constraint that should be met. Again, our objective will be to study this issue further and attempt to meet the operating temperature range and warm up time of a conventional car.

Availability. Using the statement of work definition that defines the minimum expected utilization rate as the % derived from the equation of 100 x time in service ÷ (time in service + time under repair),we have arrived at the values required to compute availability as follows:

Time in Service: Based on the average number of hours required to drive 12,208 miles (1990 JPL projection) in a 10-year period, we have selected an average speed of 30 miles per hour (Appendix A1 - Addendum 1). The time in service would thus amount to ca. 3500 hours over the 10-year period. This value would be the same for a conventional reference vehicle driven the same total distance.

The time under repair value is based on two premises. First, the time under repair for the hybrid, including routine maintenance and service, will be equivalent to the reference vehicle. Second, available data will be used to arrive at the proper values. During the tradeoff studies, these data can be further refined to reflect differences that would exist between hybrid and conventional vehicles. Our data source is a study done for DOT by Arthur D. Little, Inc.(11) This study provides data on labor hours and costs of material to perform scheduled maintenance and unscheduled maintenance and repair operations over an assumed 10-year, 100,000 mile life cycle. Unfortunately, the data is for 1974-75 model years and, thus, does not reflect the industry move toward reduced routine service requirements, as evidenced by less frequent oil changes and more lube for life fittings. An updated study is now in process for TSC with the work being done by Chilton Publishing Company. These data will update the model year coverage through the 1978 model year. We hope to be able to obtain advanced data on our reference vehicle for use in our tradeoff studies.

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(11) Data Base Development of Automobile and Light Truck Maintenance, Report No. DOT-TSC-NHTSA-78-25, issued August, 1978.

Using the available data for the 1975 model year, the data base for the 1975 version of the LTD is as follows:

	Scheduled Maintenance (hrs)	Unscheduled Maintenance (hrs)	10-Year 100,000 Mile Total	Value Used
LTD	9.175	39.500	48.675	49

Availability, thus, is as follows:

$$\text{LTD} = \frac{100 \times 3500}{3500 + 49} = 98.6\%$$

Amenities. In positioning a hybrid vehicle in the marketplace, it will be essential to offer to the buyers a wide range of optional equipment normally available in equivalent conventional driveline vehicles. This equipment offering differs by both the price class of the car and the base specifications. A list of the more significant optional offerings on a Ford LTD is given in Table 2.26.

Table 2.26 - Option List: Ford LTD

Audio - choice of 5 radio/stereo, etc.	OPT
Appearance - variety of interior and exterior appointment levels	OPT
Comfort - manual A/C, automatic temp. control	OPT
Convenience	
- Misc items incl interval wipers, mirrors, etc.	OPT
- Speed control	OPT
Performance	
- Engine options	1
- HD suspension	OPT

Option List: Ford LTD (cont'd)

Power Assists	
- Steering	STD
- Brakes	STD
- Automatic trans.	STD
- Power steering	STD

A copy of the full option lists for the LTD are enclosed as Appendix A4 to this report.

In reviewing the option availability, we foresee no difficulty in offering all the options available with each size car. The only issue is in the performance area where one must consider an approach that will make the hybrid saleable.

For the LTD, there is only one engine option, a larger displacement V-8; however, there is a need to consider not only the LTD but the other Ford products that share the same basic chassis, propulsion system, and body. By 1980 model year, the Ford LTD will share major interchangeability with the Mercury Marquis and Lincoln Continental sedans. A hybrid should appeal to the Mercury and Lincoln Continental owners if it could offer greater performance than the most fuel efficient Ford. We believe this could be accomplished by offering a larger displacement heat engine as an option on the Ford and as standard equipment on the Mercury. A turbocharged version of one of the two displacements could then be available as an option on the Ford and Mercury, and as standard equipment on the Lincoln. As our propulsion system for the LTD-based vehicle takes shape during the tradeoff studies, this issue will be reviewed and a determination made as to how to best accomplish the performance step up required.

2.9 Performance Specifications

In developing performance specifications for the near term hybrid, three factors were generally taken into account.

- JPL-specified minimum requirements.
- Operating safety.
- Driver perception of requirements, as indicated by the performance level of the LTD-based reference vehicle.

2.9.1 Minimum Non-Refueled Range

This factor relates simply to fuel tank capacity, since the range of the hybrid will not be limited by anything other than fuel tank capacity. Typically, in highway driving, a minimum cruising range of 250 miles (400 km) is desirable. Assuming this to be the range on the federal highway cycle, the range on the urban cycle was estimated at 250 km, and on the J227a(B) cycle at 150 km (although it is hard to conceive of anyone driving through a whole tank of gas on the J227a(B) cycle).

2.9.2 Cruise and Maximum Speeds

It is difficult to justify a continuous cruising speed requirement much in excess of the 55 mph speed limit; consequently, we set this equal to the JPL minimum requirement of 90 kph (56 mph).

The maximum speed requirement is determined by the ability to pass with reasonable safety. The standard high speed passing maneuver used to define passing ability involves passing a 55 ft. long truck travelling at a constant 80 kph (50 mph), clearing it by 100 ft. at the beginning and end of the maneuver. If the vehicle reaches 129 kph (80 mph) before the maneuver is completed, the

vehicle speed is held at that value for the remainder of the maneuver. Assuming that this represents a typical passing maneuver, a top speed of, say, 130 kph would be adequate. Of course, adequate acceleration capability up to this speed must also be provided; but this is, to a great extent, implied by the acceleration requirements; i.e., if a vehicle meets reasonable 0-90 kph acceleration requirements and also has a top speed of at least 130 kph, then it will have enough reserve power in the 80-110 kph range to provide adequate passing capability.

The length of time that the vehicle must maintain the top speed is a function of the passing maneuver. In general, the length of the entire maneuver is something on the order of 12-20 sec. Assuming that the driver is on a road in which passing situations are encountered repetitively, then the ability to repeat such short duration maneuvers at fairly frequent intervals may be much more significant than the ability to hold maximum speed for a long period. Consequently, rather than specify a length of time for which top speed must be held, we have chosen to specify that the vehicle must be able to complete a high speed pass maneuver, of the type described, once every five minutes, cruising at 90 kph between maneuvers, at least 10 times in succession without having the passing distance increase by more than 5%.

2.9.3 Acceleration and Gradeability

As discussed in Section 2.7, the minimum performance requirement of 0-90 kph in 15 sec represents a performance level which is on the order of 10% below that attained by the reference vehicle.

Until we get, as a result of the analyses performed in Task 2, a better idea of what the tradeoffs are of fuel consumption and operating cost against performance, we would set this performance specification, along with the other acceleration specifications, equal to the minimum requirement.

The minimum requirements for gradeability are, on the other hand, significantly below those of conventional cars (see Table 2.16) and would represent an unacceptably low performance level. As a matter of fact, the minimum acceleration requirements do imply a much higher gradeability than the minimum gradeability specified by JPL. This was determined in the following manner. Simulations were run of full throttle acceleration for both conventional and pure electric vehicles (to span the hybrid range). In both cases, the critical acceleration requirement was found to be the 0-90 kph time of 15 sec. Next, using the power-to-weight ratio for which the 0-90 kph requirement was met, the speeds at which various gradients could be climbed were computed. The results are shown on Figure 2.2 This work was also done independently by GRC; the results are shown in Figure 5.1 of Appendix A1, and they are in close agreement with those of Figure 2.2

Based on Figure 2.2, a vehicle meeting the minimum acceleration requirements would be able to negotiate a 3% grade at a speed of about 125 kph, a 5% grade at 110 kph, an 8% grade at 90 kph, and a 15% grade at 55 kph. On major highways, there are in many cases stretches of road with gradients on the order of 3-5%, on which the gradient is maintained over a long distance. To handle these cases,

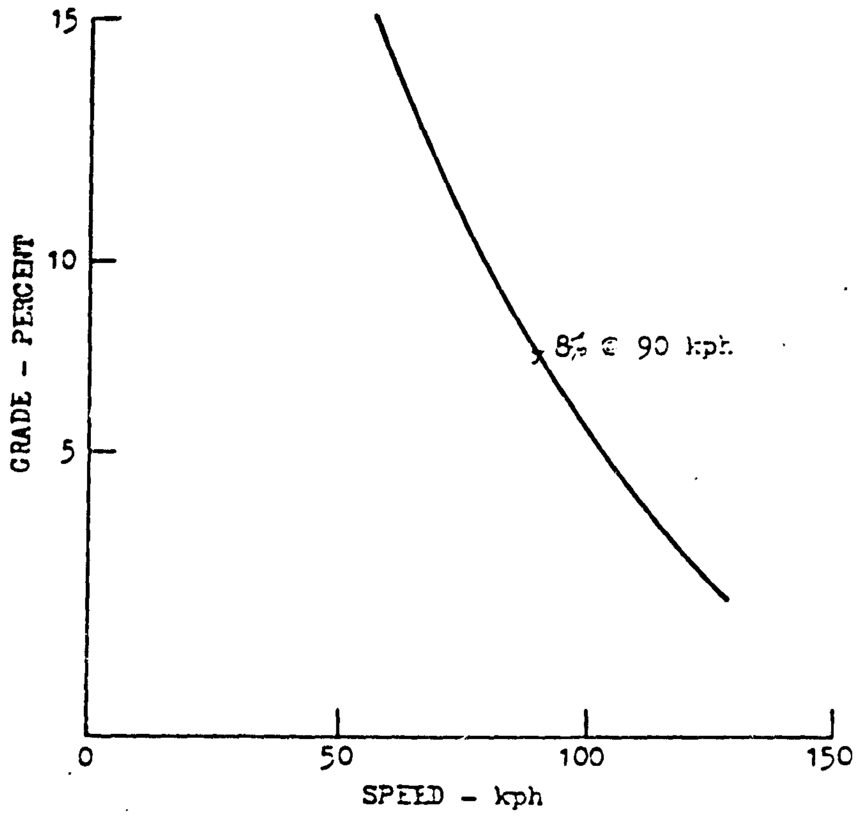

Figure 2.2 Gradeability for Vehicle Meeting Minimum Acceleration Requirements

we believe that a vehicle should be able to maintain cruising speed (90 kph) on a 3% grade indefinitely, and on a 5% grade, for at least 20 km. Grades of 8% are much less common on major highways; in this case, we would require that a vehicle be able to maintain at least 85 kph (i.e., within 5 kph of cruising speed) for 5 km, and be able to maintain 65 kph without restriction on distance. The latter would ensure the vehicle's ability to maintain a reasonable speed on extended climbs on secondary roads in mountainous regions. 15% grades are normally encountered only on secondary roads for relatively short distances. For this grade, we would require the ability to maintain 50 kph for 2 km.

Maximum gradeability is usually associated with the ability to negotiate steep driveways and other very short grades. We use the accepted value here of 30%.

Further discussion of the safety aspects of a vehicle meeting the minimum acceleration requirements will be found in Section 5 of Appendix A1. The conclusion reached by GRC and SCT is that the minimum acceleration requirements are adequate from a safety standpoint.

2.9.4 Payload and Cargo Capacity

This subject has been discussed in adequate detail in Sections 2.5.1, 2.5.2, and 2.8.1. We have specified a six passenger (two 95th % males plus four 50th % males) vehicle, with minimum interior dimensions given by Table 2.24, a minimum cargo volume of .6 m^3, and a total payload capacity of 520 kg.

2.9.5 Consumer Costs

This subject has been discussed in detail in Sections 2.4.3 and 2.8.3. In view of the large number of factors which will affect how a hybrid would actually be priced in relation to the rest of the market, and which we will be investigating during the Design Tradeoff Studies, it is premature at this point to offer anything but extremely rough numbers. These would not be particularly meaningful, so we will defer specification of consumer costs until the Design Tradeoff Studies task is complete.

2.9.6 Emissions

In this area, there is an obvious requirement to meet the federal emission standards for 1985 and the years following. These are:

HC	.41 g/mi (.25 g/km)
CO	3.4 g/mi (2.11 g/km)
NOx	1.0 g/mi (.62 g/km)

Since there is still debate over whether these requirements are too stringent, we see no point in specifying any tighter emission controls. It must be recognized, however, that the current Federal Test Procedure is inadequate to estimate the in-use emissions of a hybrid vehicle due to the fact that the hybrid can have at least two modes of operation depending on battery state of charge. If, for example, the hybrid has just two modes, then the Federal Test Procedure will have to be performed and emissions measured for both modes. Then, based on the vehicle's range on the mode on which it utilizes stored energy, and based on a typical distribution of

daily travel, the overall emissions level would be computed as an appropriately weighted average of the emissions on the two modes.

2.9.7 Ambient Temperature Capability

This subject is discussed in Section 2.8.4. Pending any further developments during subsequent tasks, we set this specification at the JPL minimum requirements.

2.9.8 Rechargeability

To bring a battery pack up to 100% state of charge (i.e., 100% of the batteries fully charged), it is generally necessary (at least for lead-acid batteries) to give the pack an equalizing charge. That is, the batteries are deliberately overcharged, allowing them to gas under a low charging current for a period of several hours. When this is done, the charging process takes longer than usual; moreover, this process should not be carried out every time the batteries are charged but at intervals of, say, every 5th to 10th charge. Otherwise, battery life is adversely affected. When the batteries are charged normally (i.e., not given an equalizing charge), they will rarely attain a true, 100% charge.

As a result of these considerations, the time to recharge must be qualified not only by a statement of where the battery is coming from (initial state of charge) but where it is going to (final state of charge). Under normal (non-equalizing) charging, the final state of charge will probably be on the order of 90%. Consequently, we have specified the recharge time to bring the battery from 80% depth of discharge to 10% depth of discharge. There is also an obvious limitation in the recharge time, based on the available power from

the wall plug and the battery capacity. For an on-board charger running off 120 V, 30 A service, a 7-hour recharge time between the 80% and 10% points is reasonable. The corresponding number for 120 V 15 A service is 14 hours, and for 240 V, 60 A service, two hours. This is a combined battery-charger efficiency of .6, an average: peak current ratio of .75, and a 16 KW battery pack.

2.9.9 Required Maintenance

As an objective, the routine maintenance for a hybrid vehicle should be no greater than equal to the reference vehicle. Available data on the reference vehicle[11] establishes that over a 10-year, 100,000 mile life, total routine service will amount to 9.175 hours which amounts to .076 hours per month.

2.9.10 Unserviced Storability

The unserviced storability of a hybrid vehicle over a specified range of ambient temperatures (-30°C to 50°C) will largely depend upon the control strategy that might be employed after prolonged storage in extreme cold ambient temperatures. As a minimum, the vehicle will be operable since the heat engine will start and provide power to propel the vehicle. The time to reach normal operating conditions will depend on the portion of heat engine output that can be diverted to charge the battery pack and, thus, raise the battery temperature. Another variable is the availability of an option that can be used in extreme cold weather to provide insulation and/or heat to the battery pack.

These issues are complex and must be considered during the design tradeoff studies. We, therefore, recommend that the issue be left open at this time and that a performance recommendation be included in the design tradeoff studies.

2.9.11 Reliability

As an objective, we believe it is reasonable to establish a reliability objective for the hybrid vehicle that is equal to the reference vehicle. The objectives that follow are based on the DOT data [11] which expresses non-scheduled maintenance in terms of frequency factor over a 100,000 mile life cycle. The objectives are:

- Mean usage between failures - powertrain = 41,000 km.
- Mean usage between failures - brakes = 55,000 km.
- Mean usage between failures - vehicle = 33,000 km.

These objectives represent the highest frequency of repair items in each category. Although this approach may be subject to question, the alternative of averaging the frequency of repair of each item within a category would distort the data. Repairs of many items are often made at the same time; and, thus, our approach is probably more indicative of actual customer experience.

2.9.12 Maintainability

The DOT data base [11] is used to establish the maintainability target for the hybrid vehicle. Our objective is to provide a hybrid that is the equal of the reference vehicle. The target below is tentative as it reflects the most recent model year (1975) in the data base. The current update study should provide more recent data to reflect the 1978 model year, data that should show significant improvement brought about by the recent emphasis by the manufacturers to reduce the need for, and frequency of, routine service.

Time to repair - mean = 9.175 hours over the life of the vehicle. The supporting detail that was used to make this projection is not

available to us; and, thus, the time to repair variance cannot be projected. In updating the data to the 1978 model year, we will endeavor to obtain this information from DOT and will incorporate it in our design tradeoff studies.

2.9.13 Availability

This area is discussed in Section 2.8.4. The projected availability is 98.6%.

2.9.14 Additional Accessories and Amenities

This area has been discussed in Section 2.8.4. As an objective, the hybrid vehicle will offer the full range of options available on a car such as the Ford LTD (Appendix A4).

The major open issue is the performance option, and this will be determined during our tradeoff studies.

3. MISSION SPECIFICATIONS

In this section, the final mission specifications resulting from the Task 1 effort are summarized. Other sections of this report which provide discussions of methodology, interim results, and other supporting data are given in parentheses at the end of each individual specification.

The distribution of daily travel for the only driver usage pattern is as follows:

Daily Travel (km)	Fraction of Total Driving	Fraction of Daily Travel on: J227(a)B	FUDC	FHDC
0–20	.0461	.204	.796	0
20–30	.0560	.082	.918	0
30–40	.0759	.058	.942	0
40–50	.0799	.045	.798	.157
50–60	.0769	.037	.652	.311
60–70	.0583	.031	.552	.417
70–80	.0672	.027	.478	.495
80–90	.0579	.024	.422	.554
90–100	.0596	.021	.378	.601
100–120	.0927	.019	.326	.655
120–140	.0653	.016	.276	.708
140–160	.0538	.014	.239	.747
160–180	.0457	.012	.211	.777
180–200	.0307	.011	.189	.800
200–220	.0226	.010	.171	.819
220–240	.0206	.009	.156	.835
240–260	.0134	.008	.144	.848
260–280	.0145	.008	.133	.859
280–300	.0104	.007	.124	.869
300–320	.0111	.007	.116	.878
> 320	.0414	.006	.109	.885

(2.2.1, 2.7, Appendix A1 Section 2)

M2 - Payload:

Typical of roomy, 6 passenger vehicle.

See item V1, Mission-Related Vehicle Characteristics.

(2.2.2, 2.7, Appendix A1 Section 3)

M3 - Trip Characteristics:

Trip characteristics are such that battery recharge once a day is possible, but not more frequently.

(2.3)

M4 - Driving Cycles:

The driving pattern on a given day is represented by:

SAE J227a(B) for daily travel up to 6 such cycles (2km).

6 J227a(B) cycles, and the remainder on FUDC, for daily travel up to 6 J227a(B) cycles + 3 FUDC's (38 km).

6 J227a(B) cycles + 3 FUDC's, and the remainder on FHDC, for daily travel beyond 38 km.

The breakdown of daily travel into these three driving cycles is also indicated under M1.

(Appendix A1 Section 7)

M5 - Annual Travel Per Vehicle:

19600 km.

(2.2.1, Appendix A1 Section 2)

M6 - Potential Number of Vehicles in Use as a Percentage of Total Fleet:

35% of 1985 in-use fleet (total)

28% of 1985 in-use fleet (potentially replaceable by hybrids)

(2.4.1, 2.4.2, Appendix A1 Section 4)

M7 - Reference Conventional ICE Vehicle:

1979 Ford LTD projected to 1985 engine and vehicle technology.

(2.5, 2.7)

M8 - Estimated Fuel Consumption of Mission Performed Entirely by Reference Vehicles:

27000×10^6 gal. (total)

21900×10^6 gal. (vehicles potentially replaceable by hybrids)

(2.5.4, 2.6)

4. MISSION-RELATED VEHICLE CHARACTERISTICS

In this section, mission-related vehicle characteristics are summarized. As before, sections of the report which provide backup data and rationale are given in parentheses for each item.

V1 - Capacity:

V1.1 – Passengers: 6 adults (2 95th % adult males and 4 50th % adult males)

Minimum interior dimensions (cm):

	Front Compartment	Rear Compartment
Headroom	96	94
Shoulder room	155	155
Leg room	105	96

V1.2 – Cargo: .6 m^3

(2.5.1, 2.5.2, 2.8.1)

V2 - Range, Speed, Acceleration, and Gradeability:

Refer to items P1-P5 in Section 5, Performance Specifications.

(2.5.3, 2.9.2, 2.9.3, Appendix A1 Section 5)

V3 - Cost Constraints:

Not defined.

(2.4.3, 2.8.3)

V4 - Ambient Conditions, Availability, & Amenities:

Refer to items P10, P16, P17 in Section 5, Performance Specifications.

(2.8.4)

5. VEHICLE PERFORMANCE SPECIFICATIONS

In this section, the performance specifications developed in Task 1 are summarized. Sections containing backup data and rationale are indicated in parentheses for each item.

P1 - Minimum Non-Refueled Range:

P1.1	FHDC	400 km
P1.2	FUDC	250 km
P1.3	J227a(B)	150 km

(2.9.1)

P2 - Cruise Speed: 90 kph

(2.9.2)

P3 - Maximum Speed:

P3.1	Maximum Speed	130 kph
P3.2	Length of Time Maximum Speed Can be Maintained on Level Road	Undefined

P3.3 High Speed Pass Capability: Vehicle must be able to perform a high speed pass maneuver, at intervals of five minutes, 10 times in succession, without the passing distance increasing by more than 5% above the value obtained with the propulsion batteries 20% discharged. This requirement is to hold throughout the entire range of battery discharge levels occurring in normal operation. The maneuver involves passing a 55' long truck travelling at a constant 80 kph, clearing it by 30 m at the beginning and end of the maneuver. Limiting speed during the maneuver is 129 kph, and initial speed is 80 kph. Following completion of the maneuver, the vehicle shall decelerate to 90 kph and maintain that speed for 4.0 minutes. It shall then decelerate and maintain 80 kph until the next maneuver. (2.9.2, Appendix A1 Section 5)

P4 - Accelerations:

P4.1	0-50 kph	6 sec max.
P4.2	0-90 kph	15 sec max.
P4.3	40-90 kph	12 sec max.

(2.5.3, 2.9.3, Appendix A1 Section 5)

P5 - Gradeability:

	Grade	Speed	Distance
P5.1	3%	90 kph	Indefinitely
P5.2	5%	90 kph	20 km
P5.3	8%	85 kph 65 kph	5 km Indefinitely
P5.4	15%	50 kph	2 km
P5.5 Maximum Grade	30%		

(2.5.3, 2.9.3, Appendix A1 Section 5)

P6 - Payload Capacity: 520 kg

(2.5.1, 2.5.2, 2.8.1, 2.9.4)

P7 - Cargo Capacity: .6 m^3

(2.5.1, 2.5.2, 2.8.1, 2.9.1)

P8 - Consumer Costs:

P8.1 Consumer Purchase Price

TBD

P8.2 Consumer Life Cycle Cost

(2.4.3, 2.8.3, 2.9.5)

P9 - Emissions - Modified Federal Test Procedures:

P9.1	Hydrocarbons (HC)	.25 g/km
P9.2	Carbon monoxide (CO)	2.11 g/km
P9.3	Nitrogen oxides (NOx)	.62 g/km

(2.9.6)

P10 - Ambient Temperature Capability:

. Temperature range over which minimum performance requirements can be met: $-20^{\circ}C$ to $+40^{\circ}C$.

(2.8.4, 2.9.7)

P11 _ Rechargeability:

Time to recharge from 80% to 10% depth of discharge.

On-board charger:	120 V, 30 A service	7 hr
	120 V, 15 A service	14 hr
Off-board charger:	240 V, 60 A service	2 hr

(2.9.8)

P12 - Required Maintenance:

Routine maintenance required per month: .076 hours per month.

(2.9.9)

P13 - Unserviced Storability:

P13.1 Duration: same as reference vehicle

P13.2 Warm up Time Required: TBD

(2.9.10)

P14 - Reliability:

P14.1 Mean Usage Between Failures - Powertrain = 41,000 km

P14.2 Mean Usage Between Failures - Brakes = 55,000 km

P14.3 Mean Usage Between Failures - Vehicle = 33,000 km

(2.9.11)

P15 - Maintainability:

P15.1 Time to Repair - Mean = 9.175 hrs over life of vehicle

P15.2 Time to Repair Variance: Data not available.

(2.9.12)

P16 - Availability:

Minimum expected utilization rate - 98.6%

(2.7.4)

P17 - Additional Accessories and Amenities:

(See Section 2.9.14 and Appendix A4)

6. LIST OF REFERENCES

(1) Peters, William Henry. Variation in Consumer Buying Behavior: An Analytical Study of Automobile Purchases. (Unpublished Ph.D. dissertation, Business Administration, Univ. of Michigan, 1968)

(2) Ibid., p. 59

(3) U. S. Department of Labor, Bureau of Labor Statistics. Consumer Expenditure Survey Series: Interview Survey 1972 and 1973, (Report 455-1, 1976)

(4) "Augmentation of Research and Analysis Capabilities for Timely Support of Automotive Fuel Economy Studies." Draft Final Report for selected task areas, NHTSA Contract No. DOT-HS-7-01790, South Coast Technology, Inc., March, 1978.

(5) H. E. Burst and R. Srock, "The Porsche 924 Body - Main Development Objectives," Porsche AG, SAE Paper No. 770311, Feb., 1977.

(6) P. Hofbauer and K. Sator, "A Diesel for a Subcompact Car," Volkswagenwerk AG, SAE Paper No. 770113, March, 1977.

(7) W. F. Marshall & K. R. Stamper, "Fuel Consumption, Emissions, and Power Characteristics of the 1975 Ford 140 CID Automotive Engine," U. S. Energy Research & Development Administration, Bartleville Energy Research Center, November, 1976.

(8) R. G. Fitzgibbons & L. H. Lindgren, Estimated Weights and Manufacturing Costs of Automobiles, Contract No. DOT-TSC-1067, Task 1 Report, Rath & Strong, Inc., 1975.

(9) "Automobile Marketing Strategies, Pricing, and Product Planning." Final Report for U. S. Department of Transportation, TSC Contract No. DOT-TS-13632, ASL Engineering, Inc. (Principal Author: H. M. Siegel), June, 1977.

(10) Executive Office of the President, Council on Wage and Price Stability, "Council Analyzes New Automobile Price Increases," November 14, 1977.

(11) Data Base Development of Automobile and Light Truck Maintenance, Report No. DOT-TSC-NHTSA-78-25, issued August, 1978.

APPENDIX A1

MISSION ANALYSIS REPORT

By

GENERAL RESEARCH CORPORATION

Internal Memorandum 2196

SELECTED DRIVING CHARACTERISTICS FOR ELECTRIC AND HYBRID VEHICLE MISSION ANALYSES

by

L. Morecraft

January 1979

Prepared Under:

Purchase Order 26
Purchase Order 5437

CONTENTS

FIGURES

TABLES

TABLES (Cont'd.)

1 INTRODUCTION

In designing a near-term hybrid vehicle, it is necessary to first establish a data base which will help to define how the vehicle will be used. The petroleum savings resulting from the use of hybrid vehicles will depend upon the portion of daily travel that can be accomplished on the stored electrical energy. Therefore, the vehicle's design must take into account how the vehicle will be driven: the vehicle's daily range, the frequency of trips, the speed it must attain, the terrain it crosses, where it is parked and so forth. This report contains data which describe the travel patterns of drivers and how they use their vehicles.

To determine the minimum requirements for range, speed, and capacity in typical kinds of driving, a previous GRC study[1] made a detailed new analysis of existing travel data. To delineate the detailed distributions of range and trip frequency, the original data tapes from two extensive urban origin-destination travel surveys[2,3] were processed. Los Angeles was chosen for analysis because of its size and its historic dependence on automotive travel. Washington, D.C. was selected because its survey was made at about the same time as the Los Angeles survey and because it differs from Los Angeles in potentially important ways: it is much smaller, and much more dependent on public transportation. Data from these two surveys correlate well with transportation data taken from other sources. Therefore, when the data from each survey are taken together, the result indicates a range of vehicle use representative of driving in urban areas across the country.

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[1] W. F. Hamilton, Prospects for Electric Cars, General Research Corporation CR-1-704, November 1978.

[2] LARTS Base Year Report: 1967 Origin-Destination Survey, Transportation Association of Southern California, Los Angeles, December 1971.

[3] The Home Interview Survey - What and Why, National Capital Region Transportation Planning Board, Washington, D.C., February 1968.

The bulk of the detailed data in this report is based on the Los Angeles and Washington, D.C. origin-destination surveys, but a number of other sources were also utilized including the Nationwide Personal Transportation Study (1969),[1] the 1974 National Transportation Study,[2] the Federal Highway Administration's publication Highway Statistics[3] and others.

The design of the hybrid vehicle is to be based on specific vehicle uses or "missions." Previous examination of the travel data has lead to the division of drivers into three groups with widely differing travel patterns: primary, secondary, and only drivers, No other groups of drivers were clearly distinguisable on the basis of their reported travel. Primary and secondary drivers are from multi-car, multi-driver households, where the primary driver is defined as the driver who travels the greatest distance each day. Secondary drivers are the other drivers at multi-driver households. The only driver is from a one-car, one-driver household. Drivers sharing a car were not included in the data processed. Drivers in each of these classes use their cars differently and require different capabilities of their vehicles; that is each driver class performs a different "mission". Wherever possible, the travel data in this report has been split out by these three driver classes. It is interesting to note that the data for the only driver class is very close to the average for all drivers taken together. Information on another specific vehicle use, taxis, is also included in a separate section.

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[1] Nationwide Personal Transportation Study, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., April 1972.

[2] 1974 National Transportation Study, U.S. Department of Transportation, Washington, D.C., February 1975.

[3] Highway Statistics, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., Annual.

In addition to data on vehicle travel, this report also contains information on cargo capacity, availability of off-street parking (as required for battery recharging) and accident involvement rates based on the acceleration and gradeability capability of the hybrid vehicle.

2 DISTRIBUTIONS OF DAILY TRAVEL

2.1 TRAVEL LESS THAN SPECIFIED RANGE

Daily travel data were derived from the Los Angeles and Washington, D.C. origin-destination surveys. Distributions of reported driving distance for the three driver groups are shown in Table 2.1. The columns contain cumulative percentages, with the left-hand figure representing Los Angeles data, the right, Washington, D.C. Each distribution is displayed graphically in Figs. 2.1-2.3 with the lower edge of each band corresponding to the Los Angeles data points. The Los Angeles and Washington data do not show the length of trips beginning or ending outside the urban area. Thus, Table 2.1 and Figs. 2.1-2.3 apply only to urban driving. Roughly, one percent of all trips reported on the survey day began or ended outside the survey areas. The data do not account for long distance travel, such as vacation trips, made by 63 percent of households. A GRC report[1] has estimated that 35 percent of personal cars take round trips in excess of 320 km. Also the distributions cannot be applied to rural drivers who tend to drive greater distances than urban drivers.

The distributions were developed from information on individual trips during the survey day; therefore the data refer to the distribution of a number of drivers on a single day. If the assumption is made that the drivers form a homogeneous group (checks within each driver groups revealed no significant differences), the data also give the distribution of travel by an individual driver over many days.

Column set A shows the distributions of travel reported by drivers on the survey days. In Washington, the travel per driver was considerably less than in Los Angeles, and the difference is greater at the longer ranges as might be expected from the smaller size of the Washington region, which limits the opportunities for long urban trips in a single day. The average daily distance per driver is 50 km for Los Angeles and 33 km for Washington, D.C.

[1] M.M. Collins, Automobile and Light Truck Range Requirements (draft), General Research Corporation IM-2193, December 1978.

TABLE 2.1

DISTRIBUTIONS OF DAILY TRAVEL VERSUS DISTANCE IN

LOS ANGELES AND WASHINGTON, D.C.

Driving Distance, km	A Percent of Drivers Reporting Less Than Specified Driving Distance			B Percent of Total Driving Distance By Drivers Reporting Less Than Specified Driving Distance			C Percent of Total Driving Distance Less Than Specified Driving Distance		
	Secondary	Only	Primary	Secondary	Only	Primary	Secondary	Only	Primary
10	23.5-32.1	17.0-20.3	3.3-5.3	4.9-7.9	2.0-3.3	0.3-0.7	32.2-41.0	19.7-28.1	12.7-20.4
20	49.6-59.3	35.4-41.4	11.5-16.3	18.7-27.5	7.9-13.2	1.9-4.2	54.7-67.2	35.4-49.5	24.6-39.0
30	67.2-77.8	50.5-59.4	21.8-33.3	34.2-49.8	15.9-27.0	5.2-13.0	69.3-82.3	47.5-64.8	35.3-54.7
40	78.1-87.9	61.0-72.7	32.5-49.4	47.7-66.9	23.7-41.4	10.0-24.7	79.0-90.5	56.9-75.2	44.6-66.9
50	85.4-93.3	69.5-80.9	42.8-63.4	59.4-78.7	31.8-52.8	15.9-37.8	85.5-95.0	64.2-82.5	52.6-76.0
60	90.3-96.6	75.7-86.8	51.7-74.0	69.0-87.5	39.1-62.8	22.2-49.9	89.8-97.4	70.1-87.4	59.4-82.4
70	93.6-98.4	79.9-91.1	59.5-81.5	76.6-93.1	44.9-71.5	28.6-60.0	92.6-98.6	74.8-90.8	64.9-87.0
80	95.6-99.0	83.9-93.9	65.8-86.7	82.0-95.3	51.3-78.0	34.7-68.2	94.6-99.2	78.7-93.2	69.8-90.3
90	96.9-99.6	86.9-95.7	71.1-90.7	85.9-97.8	56.7-82.7	40.5-75.2	95.9-99.6	81.8-94.7	73.8-92.7
100	97.6-99.8	89.4-96.9	75.5-93.2	88.3-98.7	61.7-86.3	45.8-80.2	96.9-99.7	84.3-95.9	77.2-94.4
120	98.7-99.9	92.4-98.3	82.1-96.2	92.6	68.7-91.0	55.1-87.0	98.2	88.1-97.3	82.6-96.5
140	99.3	94.3-98.9	86.6-97.8	95.4	73.9-93.4	62.6-91.3	98.9	90.9-98.1	86.7-97.7
160		95.9-99.2	89.4-98.4	96.5	79.0-94.7	67.9-93.1		93.0-98.7	89.6-98.5
180		96.7-99.6	91.8-99.0	97.6	81.8-96.8	73.1-95.3		94.4-99.1	92.0-99.0
200		97.4	93.7-99.4	99.0	84.7-97.4	77.8-96.8		95.8-99.3	94.0-99.3
220		98.1	95.2-99.6		87.8-98.1	81.8-97.7		96.7	95.4-99.5
240		98.6	96.2		90.3	84.8-98.2		97.4	96.5-99.7
260		98.8	97.2		95.4	88.0-98.7		97.7	97.3-99.8
280		99.1	97.8		96.5	90.0		98.3	97.9
300		99.2	98.4		97.6	92.3			98.5

Source: Los Angeles and Washington, D.C., Origin-Destination Surveys

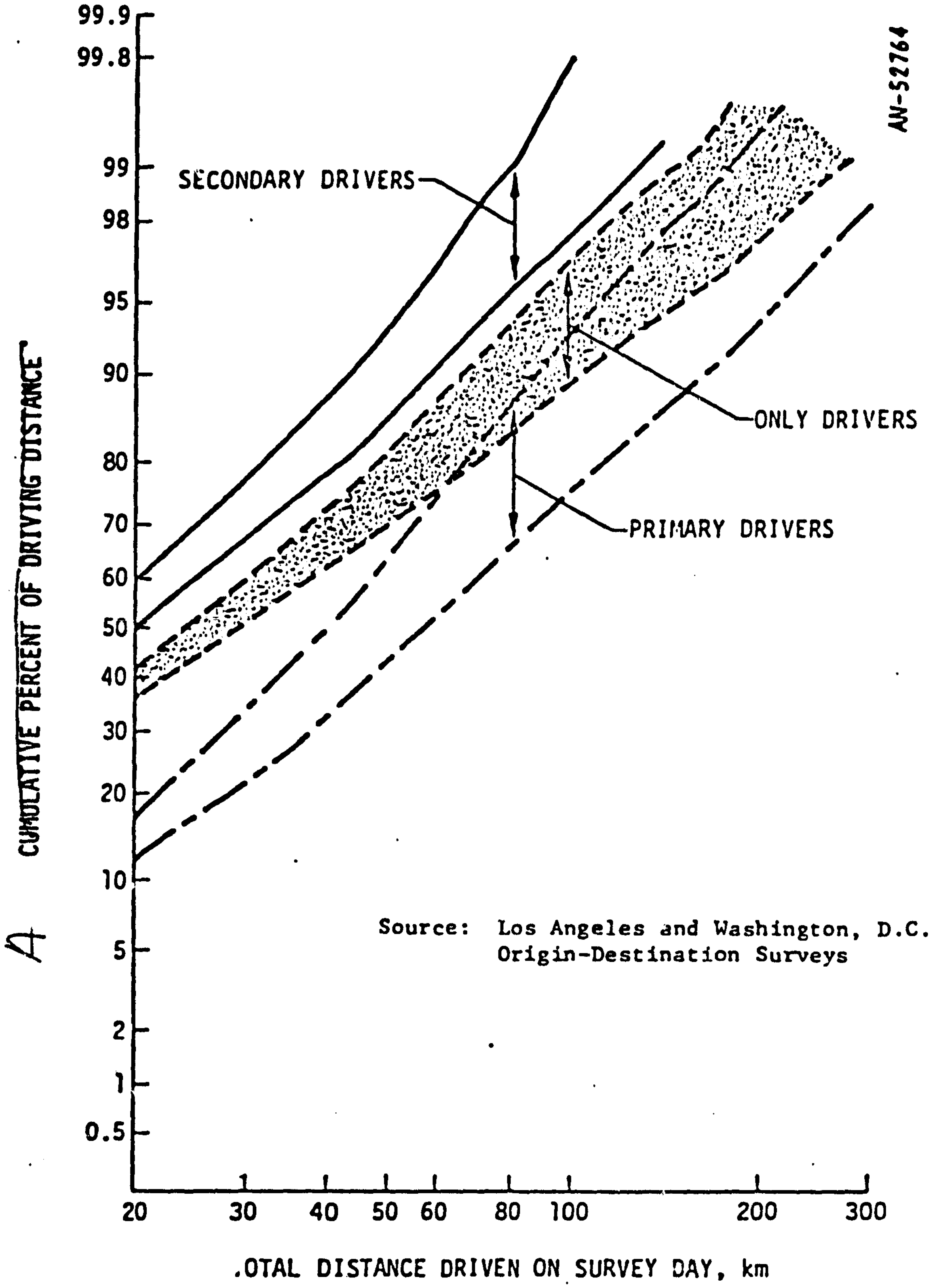

Figure 2.1. Percent of Drivers Reporting Less Than the Specified Driving Distance

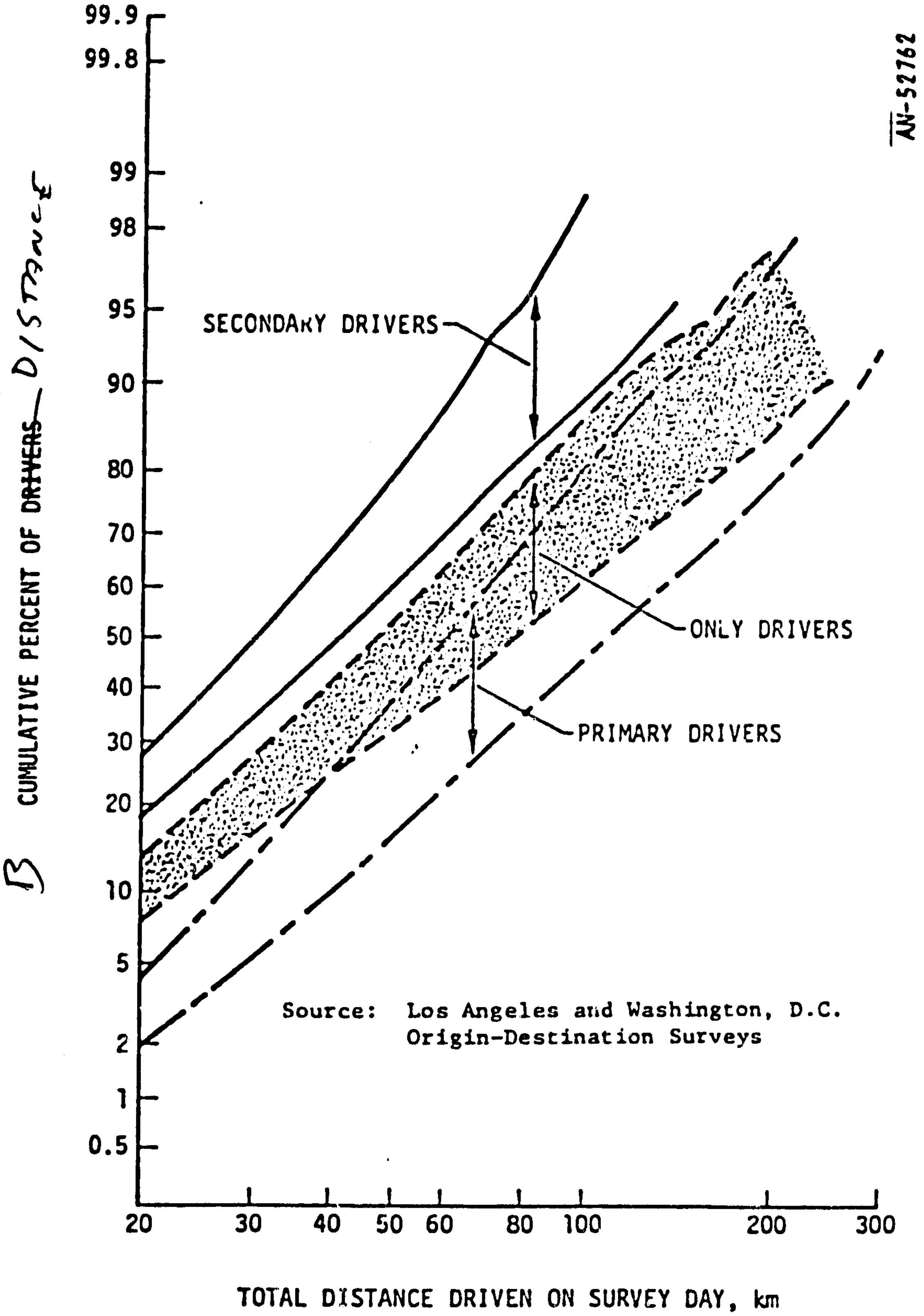

Figure 2.2. Percent of Driving Distance By Drivers Reporting Less Than Specified Driving Distance

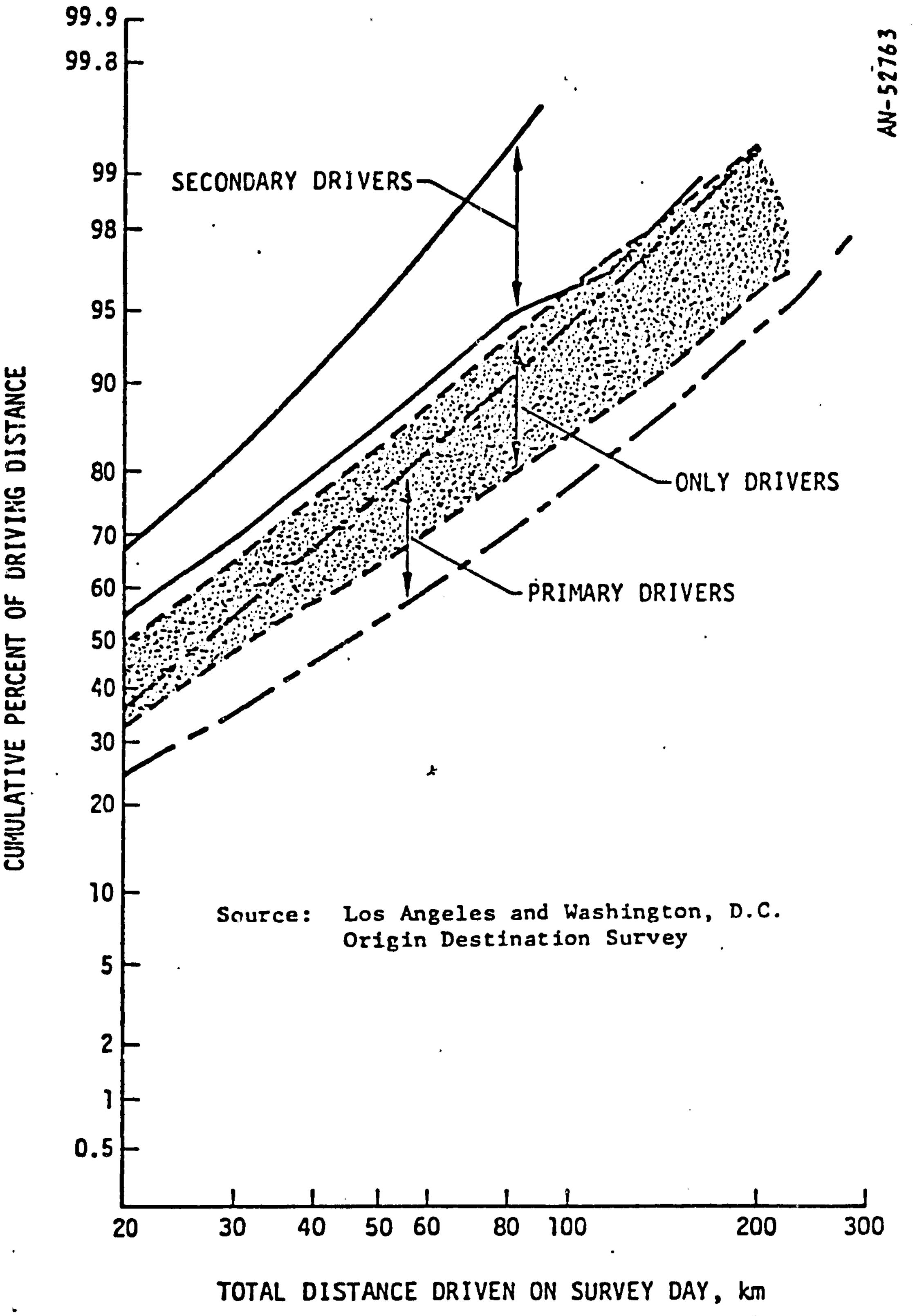

Figure 2.3. Percent of Total Driving Distance Less Than Specified Driving Distance

The second set of columns (B) shows the percent of total travel reported by drivers who drove less than a given distance. This data indicate the percentage of total driving distance which could be accomplished by range-limited (e.g., electric) cars. Even if a car of this range were useless on all other days requiring more travel, it could serve this percentage of total driving distance.

Column set C shows the percent of all driving within a specified range. This data indicates the percent of total driving distance which could be accomplished on an electric propulsion system of a given range in a hybrid car. The distribution assumes that the entire electric range is useful on every day requiring a longer total range.

Table 2.2 shows the average daily and annual ranges and the annual range of the 95th and 98th percentile dirvers in Los Angeles and Washington. When working with the assumption that the distributions of daily travel in Table 2.1 can be used to represent travel by one driver over many days, annual ranges cannot be directly calculated by multiplying the daily driving distance by 365. A 95th percentile driver on the survey day is expected to drive as far on only 5 percent of his driving days.

If we assume that each driver's travel is uncorrelated from day to day, the Central Limit Theorem says that the mean and variance of the annual travel will be 365 times the mean and variance of the daily travel.

The mean and variance of the daily travel can be calculated directly from the distributions in Table 2.1 using the technique shown in the appendix. Once the mean and variance of daily travel are known, the 95th and 98th percentile distances are found with the aid of standard normal (Gaussian) distribution tables. The 95th and 98th percentile points occur at 1.645σ and 2.054σ respectively, where σ is the standard deviation. For example,

TABLE 2.2

DAILY AND ANNUAL DRIVING DISTANCE

Type of Driver	Daily Driving, km: Average Daily Range, Survey	Daily Driving, km: Average Daily Range, Derived	Daily Driving, km: Standard Deviation	Annual Driving, km: Standard Deviation	Annual Driving, km: Average	Annual Driving, km: 95th Percentile	Annual Driving, km: 98th Percentile
Secondary							
Los Angeles	27.9	27.7	25.1	480	10,100	10,887	11,083
Washington	20.5	20.6	17.3	331	7,534	8,076	8,211
Only							
Los Angeles	47.0	46.4	50.8	971	16,947	18,542	18,941
Washington	32.2	32.0	28.6	546	11,682	12,582	12,803
Primary							
Los Angeles	78.1	76.8	63.5	1,213	28,045	30,042	30,536
Washington	48.0	47.8	33.9	648	17,462	18,526	18,793

if the mean and variance of the daily travel distribution are 35 km and 800 km^2, then the mean and variance of the annual travel are 12,775 (= 365 × 35) km and 292,000 (= 365 × 800) km^2. The standard deviation of annual travel is only 540 km (= $292{,}000^{1/2}$) so the 95th and 98th percentile travel ranges are 13,664 km and 13,885 km.

Note that the above approach leads to a distribution of annual driving which is relatively narrow, i.e., the ratio of standard deviation to average is small. This occurs because the average increases as N while the standard deviation increases as $N^{1/2}$, where N is the number of days (365 in this case).

In Table 2.2 both the survey and derived daily ranges are included for comparison. Note that these ranges are essentially the same for each comparable case. This serves as a check on both the consistency of the tabular distributions and the method used to derive the mean (average) and variance of the daily driving distribution.

As mentioned earlier, the derived annual distributions are relatively narrow. The actual distributions are undoubtably wider for several reasons. One, the survey only recorded trips which were taken entirely within the survey area, thus excluding some long trips. Two, the survey may not have accurately sampled drivers who are constantly on the road for their livelihood, e.g., salesmen, truck drivers, etc. And three, the assumption that all drivers on the survey day give accurate statistics for a driver on all days may introduce appreciable errors at the extreme driving ranges.

A number of studies have collected data on the average distance traveled. Table 2.3 shows the average annual vehicle kilometers traveled per personal passenger vehicle as estimated by several sources. The overall average is about 16,000 kilometers per vehicle, and has remained reasonably constant throughout the years surveyed. The annual kilometers estimated from the Los Angeles and Washington, D.C. are within the range of estimates provided by other studies.

TABLE 2.3

PERSONAL PASSENGER VEHICLE ANNUAL TRAVEL

Source	Data Year	Annual Vehicle Kilometers Traveled
Los Angeles Origin-Destination Survey	1967	16,947
Washington, D.C. Origin-Destination Survey	1968	11,682
Nationwide Personal Transportation Study	1969	18,676
JPL Estimate for Hybrid Vehicle Study (Based on NPTS)	1975	17,466
Highway Statistics (FHWA)	1969	15,749
	1970	16,065
	1971	16,295
	1972	16,396
	1973	16,087
	1974	15,285
National Transportation Study	1972	
Large Cities (23)*		
Average		15,298
Range		11,011 - 20,983
Smaller Cities (23)†		
Average		17,555
Range		9,415 - 21,044

*Cities with 1972 population over one million.

†Cities with 1972 population between 250,000 and 500,000.

2.2 TRIP FREQUENCY AND AVERAGE TRIP DISTANCE

The distribution of the number of driver trips per day shown in Table 2.4 was developed from the Los Angeles and Washington, D.C. origin-destination surveys. The data indicate that the 95th percentile only drivers in Los Angeles average five more trips per day than Washington only drivers while covering 62 more kilometers (see Table 2.5). Dividing the daily range by the number of trips would indicate that the average trip distance in Washington, D.C. (11.3 km) is about the same as in Los Angeles (12.3 km).

The actual joint distribution of trip frequency and trip distance has not been calculated. Examination of the 10 percent of secondary drivers who make the longest trips reveals that they make both longer trips and more frequent trips per day.

The Nationwide Personal Transportation Study found that over half of daily trips are less than 8 kilometers long. Of the 23 large cities examined from the 1974 National Transportation Study, the average trip distance was 10.6 kilometers; in smaller cities the average was 8.2 kilometers.

2.3 FREEWAY TRAVEL

The data on the percent of urban travel on freeways, presented in Table 2.6 were obtained from the 1974 National Transportation Study. The information is from a previous GRC report[1] which processed data from 46 geographically distributed cities, 23 large cities with populations over one million (1972) and a like number of smaller cities with one-quarter to one-half million in population.

The overall city average puts the portion of travel on freeways at about 28 percent; but the range is quite large, varying from less than

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[1] M. M. Collins and L. Morecraft, Applicability of Existing Regional Data to National Impact Analysis for Urban Electric Cars, General Research Corporation IM-2045, June 1976.

TABLE 2.4

DISTRIBUTIONS OF DRIVER TRIPS PER DAY

Trips per Day	Secondary		Only		Primary	
	Los Angeles	Washington	Los Angeles	Washington	Los Angeles	Washington
1	1.9	3.2	1.5	2.8	0.9	1.0
2	40.9	63.9	36.2	55.9	26.5	43.7
3	51.8	68.9	44.5	61.7	31.7	48.6
4	65.1	87.8	58.6	83.2	45.8	73.0
5	75.4	90.0	69.5	85.8	55.3	76.7
6	81.1	95.6	76.8	92.8	63.4	86.8
7	86.4	96.3	82.1	94.2	70.8	88.9
8	89.9	98.2	86.7	96.7	76.1	93.3
9	92.5	98.5	89.4	97.3	80.5	94.5
10	94.5	99.3	92.3	98.3	84.7	96.2
11	95.8		93.9	98.7	87.2	96.6
12	96.8		95.3	99.1	89.6	97.6
13	97.7		96.4		91.8	98.0
14	98.3		97.2		93.4	98.6
15	98.9		97.7		94.3	98.9
16	99.1		98.2		95.3	99.1
17			98.5		96.1	
18			98.8		96.9	
19			99.1		97.4	
20					97.9	
21					98.2	
22					98.6	
23					98.8	
24					98.9	
25					99.1	

Source: Los Angeles and Washington, D.C. Origin-Destination Survey

TABLE 2.5

DAILY RANGE AND TRIPS PER DAY

	Daily Range 95th Percentile, km	Daily Range 98th Percentile, km	Trips per Day 95th Percentile	Trips per Day 98th Percentile
Secondary Drivers				
Los Angeles	77	105	10	14
Washington	54	67	6	8
Only Drivers				
Los Angeles	147	218	12	16
Washington	85	113	7	10
Primary Drivers				
Los Angeles	218	285	16	20
Washington	110	145	9	13

Source: Los Angeles and Washington, D.C. Origin-Destination Surveys

TABLE 2.6

PERCENT OF TRAVEL ON FREEWAYS

	Percent Freeway Travel
Los Angeles	38.6
Washington, D.C.	38.2
Large City Average	33.5
Small City Average	23.1
Total Average (46 cities)	28.3
Range	7.4 - 54.2

Source: FHWA's 1974 National Transportation Study

10 to over 50 percent freeway driving. As might be expected, smaller cities, which would have less developed highway systems, show about 10 percent less freeway driving than the large cities. The data point for Washington, D.C. seems suspiciously high, since the only major freeway system at the time was the Beltway which encircles the city, but the 39 percent freeway travel in Los Angeles agrees well with other data sources.

2.4 TRAVEL SPEED

The average travel speeds on freeways and surface streets shown in Table 2.7 were gathered from the 1974 National Transportation Study. Average speeds are higher in smaller cities, most likely a reflection of traffic density. The travel speeds are taken to be the 24 hour average moving speed attained on the roadway, as the speeds here are considerably higher than other estimates obtained by dividing trip distances by trip times, which would include time stopped at intersections, etc. (as do the SAE and Federal driving cycles). These data were collected prior to the 1974 imposition of the 55 mph speed limit; present speeds would be expected to be slightly lower for freeway driving.

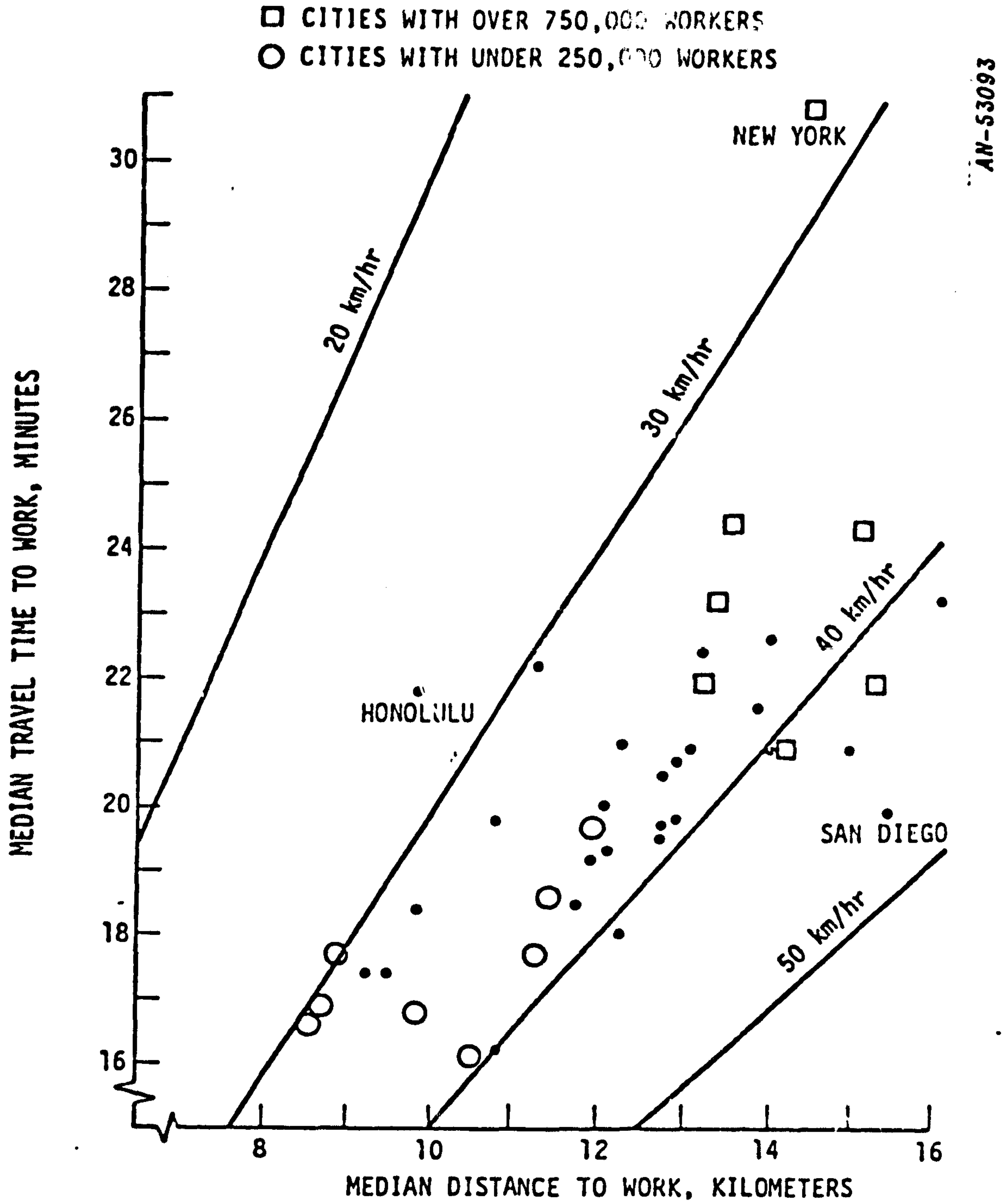
The 1974 Highway Statistics contains data on the average speed of passenger cars on urban primary and secondary roads and suburban primary roads. These data show lower speeds on primary roads reflecting the imposition of the 55 mph speed limit. Data on median time and median distance to work for various cities are shown in Fig. 2.4. As would be expected, workers in smaller cities travel shorter distances to their place of employment and workers in larger cities spend a greater amount of time commuting. Of the 41 cities surveys[1], the great majority lie between the 30 km/hr and 40 km/hr lines in Fig. 2.4. This would be a good indication of the average speeds attained during the peak traffic hours.

[1] Selected Characteristics of Travel to Work in 20 Metropolitan Areas: 1975 and 1976, U.S. Department of Commerce. Bureau of the Census, Series P-23, No. 68, February 1978 and Series P-23, No. 72, September 1978.

TABLE 2.7
AVERAGE SPEED

	Freeway, km/hr	Surface Street, km/hr
National Transportation Study Data (1972):		
Los Angeles	88.6	46.7
Washington, D.C.	86.9	48.3
Large City Average	81.2	43.6
Smaller City Average	86.9	47.7
Total Average (46 cities)	84.1	45.6
Range	61 - 106	32 - 69

	Average Speed of Passenger Cars, km/hr
1974 Highway Statistics Data:	
Urban Primary Roads	68.4
Urban Secondary Roads	52.2
Suburban Primary Roads	77.1



Source: Census Bureau's Selected Characteristics of Travel to Work in 20 Metropolitan Areas 1975 and 1976.

Figure 2.4. Median Travel Time for Work Travel in a Vehicle

3 CHARACTERISTICS OF VEHICLE USE

3.1 TRIP PURPOSE

The best information available on this purpose is from the 1969 Nationwide Personal Transportation Study. These data have already been compiled in the JPL Hybrid Vehicle Potential Assessment[1] report. Rather than complicate the issue with data from other, less complete sources, the JPL table is reproduced in Table 3.1.

Work trips are the major recurring class of trips accounting for 36 percent of all trips and 42 percent of vehicle travel annually. Social and recreational trips are shorter and less frequent (22 percent of trips) than other trips but still account for a third of the distance traveled each year.

3.2 VEHICLE OCCUPANCY

The number of vehicle occupants (driver plus passengers) noted in the Los Angeles and Washington studies is presented in Table 3.2. According to these data, the passenger requirements of over 95 percent of trips could be fulfilled by a four-seated car. A five-passenger car which would satisfy the space needed for about 98 percent of all trips. The JPL study[1] includes vehicle occupancy data broken out by trip purpose. This information from the Nationwide Personal Transportation Study is reproduced in Table 3.3.

3.3 CARGO PAYLOAD

The trunk or cargo space figures for all car models (excluding station wagons and two-seaters) were taken from the EPA's 1978 California Gas Mileage Guide.[2] Table 3.4 shows the average cargo space along with the range of trunk sizes available in each car class. The

[1] F. Surber, Hybrid Vehicle Potential Assessment, Interim Progress Report, Draft, Jet Propulsion Laboratory 5030-162, Pasadena, California, February 1978.

[2] 1978 Gas Mileage Guide, California, U.S. Department of Energy, U.S. Environmental Protection Agency, Washington, D.C. February 1978.

TABLE 3.1

HOUSEHOLD TRAVEL DISTRIBUTION BY TRIP PURPOSE

Source: JPL's Hybrid Vehicle Potential Assessment

Trip Purpose	Percent of automobiles		Trip length	Trip rate per household		Vehicle-Kilometers per household	
	Trips	Travel	(km)	Annual	Daily	Annual	Daily
Earn a living							
Home-to-work	31.9	33.7	15.0	445	1.2	6693	18.4
Related business	4.3	7.9	25.8	61	0.2	1573	4.3
Subtotal	36.2	41.6	16.3	506	1.4	8265	22.7
Family business							
Shopping	15.2	7.5	7.0	213	0.6	1486	4.2
Medical and dental	1.8	1.6	13.4	24	0.1	323	0.8
Other	14.0	10.2	10.4	195	0.5	2032	5.6
Subtotal	31.0	19.3	9.0	432	1.2	3841	10.6
Civic, educational and religious	9.3	4.9	7.5	130	0.4	979	2.6
Social and recreational							
Visiting friends and relatives	8.9	12.1	19.2	125	0.3	2395	6.6
Pleasure driving	1.4	3.1	30.2	19	0.1	610	1.6
Vacations	0.1	2.5	256.0	2	0.05	512	1.4
Other	12.0	15.3	18.2	166	0.4	3034	8.3
Subtotal	22.4	33.0	21.0	312	0.8	6552	17.9
Other and unknown	1.1	1.2	15.0	16	(2)	240	0.6
Total	100.0	100.0		1396	3.2	19878	54.4

TABLE 3.2

VEHICLE OCCUPANCY

	Driver Class					
	Secondary		Only		Primary	
Percent Carrying at Most N Passengers (including driver)	Los Angeles	Washington	Los Angeles	Washington	Los Angeles	Washington
N = 1	66.2	67.9	66.1	68.1	52.9	58.1
N = 2	84.1	85.6	88.2	88.9	79.1	83.8
N = 3	92.4	93.7	94.4	95.3	89.0	92.1
N = 4	96.8	97.3	97.5	98.3	95.3	96.6
N = 5	98.6	98.8	99.0	99.2	97.8	98.6
N = 6	99.3	99.6	99.5	99.7	99.0	99.5

Source: Los Angeles and Washington, D.C. Origin-Destination Surveys

TABLE 3.3

DISTRIBUTION OF AUTOMOBILE TRIPS BY NUMBER OF OCCUPANTS FOR EACH PURPOSE OF TRAVEL - RESIDENTS OF STANDARD METROPOLITAN STATISTICAL AREAS

Source: JPL's Hybrid Vehicle Potential Assessment

Number of occupants	Major purpose of trip: Earning a living			Family business				Educational, civic, and religious	Social and Recreational					All purposes
	To and from work	Related business	Total	Medical and dental	Shopping	Other	Total		Vacation	Visits to friends or relatives	Pleasure rides	Other	Total	
	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent*	Per-cent	Per-cent	Per-cent	Per-cent	Per-cent
1	74.5	62.9	73.2	38.5	43.7	45.9	44.4	33.7	*	36.3	17.0	27.3	30.1	30.9
2	17.6	24.7	18.4	38.2	34.0	31.2	33.0	26.5	*	31.4	41.1	36.0	34.5	22.3
3	4.1	7.5	4.5	12.6	11.5	12.5	12.0	15.8	*	14.8	13.2	12.7	13.6	9.9
4	1.6	2.6	1.8	4.2	6.1	4.7	5.4	10.8	*	8.9	16.2	11.2	10.6	5.7
5	1.0	0.8	1.0	2.2	2.5	3.1	2.7	5.5	*	4.1	7.8	5.2	5.1	2.9
6	0.4	0.5	0.4	3.7	0.8	1.3	1.1	3.6	*	2.2	2.0	4.0	3.2	1.5
7	0.1	--	--	0.3	0.8	0.6	0.7	1.6	*	1.3	2.5	1.5	1.5	0.7
8	0.1	0.1	0.1	--	--	--	--	0.6	*	0.3	--	0.6	0.4	0.2
9 or more	--	0.3	--	--	0.3	0.1	0.2	0.5	*	0.3	--	1.0	0.5	0.3
N/A	0.6	0.6	0.6	0.3	0.3	0.6	0.5	1.4		0.4	0.2	0.5	0.5	0.6
Total	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Total number (000) of daily trips	53,033	6,716	59,749	2,755	25,937	21,407	50,099	14,844	244	14,068	2,036	20,038	36,435	163,954

* Available data not sufficient for analysis

SOURCE: Based upon unpublished table P-8 from the Nationwide Personal Transportation Survey conducted by the Bureau of the Census for Federal Highway Administration, 1969-1970.

larger spaces are associated with hatchback models. Weighting the average cargo space by the sales in each class yields an average cargo space of 0.44 m^3 for cars sold. The 95th percentile space is 0.62 m^3, the 98th percentile is 0.65 m^3. These statistics do not necessarily represent the desired cargo space, since this dimension is only one of many features figuring into the car-buying decision

TABLE 3.4
CARGO SPACE AVAILABLE
1978 MODEL CARS*

	Average Space, m^3	Space Range, m^3
Subcompacts	0.28	0.14 - 0.51
Compacts	0.40	0.28 - 0.59
Mid-sized	0.46	0.40 - 0.57
Large-sized	0.58	0.48 - 0.65

Sales Weighted Average	0.44 m^3
95th Percentile Cargo Space	0.62 m^3
98th Percentile Cargo Space	0.65 m^3

*Station wagon and two-seater model excluded.

Source: EPA's 1978 Gas Mileage Guide, California

4 VEHICLE LOCATION

The figures in this section have been estimated from data collected in the Census Bureau's Annual Housing Survey.[1] The survey questionnaire asked for the number of cars available to the household, but does not define the term "available". Presumably "available" would include not only cars owned by and registered to the household members, but also leased, rented, and borrowed cars and company or fleet cars available for personal use.

The automobile data are split into those at one-car households and those at multi-car households. This division does not exactly match the breakout of driver classes (i.e., only drivers and primary/secondary drivers) because the origin-destination survey data reported here excluded households where drivers shared a car. Therefore, the number of one-car households is greater than the number of only drivers, since one-car households with more than one driver were eliminated from the data. Yet reasonable estimates can be obtained by ignoring this distinction because of the low occurrence of vehicle sharing. In Los Angeles, only 12 percent of drivers reporting trips came from households where sharing a vehicle was necessary. In Washington, only 9 percent of drivers shared a car. These percentages will decline in the future; as automobile ownership continues to rise; nearly every driver will have his own car.

In this section, the term "Urban area" refers to Standard Metropolitan Statistical Areas (SMSAs), each of which consist of a county or group of counties that contain one or more central cities with populations over 50,000.

4.1 AVAILABILITY OF CARS WITH OFF-STREET PARKING

Since off-street parking is required for residential recharging, it is necessary next to estimate the number of cars available with

[1] Annual Housing Survey, U.S. Department of Commerce, Bureau of the Census, and U.S. Department of Housing and Urban Development, Washington, D.C., Annual.

off-street parking. The estimates must also distinguish between cars at single-family units and at multi-family units, where recharging facilities may be more difficult to obtain, and between cars serving the three major classes of drivers: secondary, primary, and only drivers. Recently-published reports of the Annual Housing Survey summarize this information for owner- and renter-occupied units, together with the availability of cars at these units.

All housing units in Survey reports are broken down according to whether they are occupied by owners or renters. Furthermore, detailed tabulations are available only for certain specific types of housing units. "Specified owner-occupied" units are owner-occupied single-family homes on ten acres or less, with no business on the property. "Specified-renter-occupied" units include most renter-occupied units, but exclude single-family renter-occupied units on ten acres or more.

As Table 4.1 indicates, these two classes of occupied units amount to substantially less than the national total--about 15 percent less. The remaining units are largely rural single-family rentals, single-family owner-occupied homes on ten acres or more, or with a business on the property, and owner-occupied multi-family housing units. To include the units omitted in the two classes for which parking availability is published, it is necessary to extrapolate from Table 4.1. The results of such an extrapolation are summarized in Table 4.2.

The extrapolation was made in three steps. First, specified renter-occupied housing units were simply scaled up, assuming that the added units were like those tabulated, to give totals for all renter-occupied housing units. The necessary scaling factor is very near unity for this step. Second, single-family units which were renter-occupied were subtracted from the renter categories and added to specified owner-occupied units to approximate all single-family housing units. For this step, the single-family renter-occupied units were assumed to have the same numbers of cars per unit, and the same availability of off-street parking, as the specified renter-occupied units. This tends to

TABLE 4.1

REPORTED AVAILABILITY OF CARS AND OFF-STREET PARKING, 1974

	Housing Units, thousands	Percent Units with:				Cars Available		Units with Parking, percent
		No Car	1 Car	2 Cars	3 or More Cars	Total, thousands	:r Unit	
All Occupied Housing Units	70,830	17	48	28	7	88,197	1.25	-*
Specified Owner-Occupied**	36,154	8	45	37	10	53,681	1.48	75†
Specified Renter-Occupied††	24,292	31	50	17	2	22,065	.91	91§
Occupied Units in SMSAs	48,674	18	46	30	7	61,129	1.26	-
Specified Owner-Occupied	25,057	8	42	40	10	38,637	1.54	77
Specified Renter-Occupied	18,800	32	49	17	2	16,710	.89	92
Occupied Units Outside SMSAs	22,156	15	54	25	6	27,070	1.22	-
Specified Owner-Occupied	11,097	11	51	30	8	15,042	1.36	69
Specified Renter-Occupied	5,491	25	54	18	2	5,355	.98	87

* Not tabulated

** Includes only one-family homes on ten acres or less with no business on property

† With garage or carport on property

†† Excludes one-family homes on ten acres or more

§ Off-street parking facilities included in rent

Source: US Bureau of the Census, Annual Housing Survey: 1974, Parts A and C

TABLE 4.2

ESTIMATED AVAILABILITY OF CARS AND OFF-STREET PARKING

	United States	Outside SMSAs	In SMSAs: Total	In SMSAs: In Central Cities	In SMSAs: Outside Central Cities	Los Angeles Long Beach SMSA	Washington DC SMSA
Population, thousands	211,391	56,427	154,964	-	-	6,926	3,015
Occupied Housing Units, thousands	70,830	19,586	48,674	22,566	26,109	2,520	981
With Parking, percent	83	77	85	86	84	94	71
Single Family, percent	63	75	61	52	70	61	56
With Parking, percent	78	73	80	80	79	94	54
Multifamily, percent	37	25	39	48	30	39	44
With Parking, percent	91	87	92	93	91	94	93
Persons Per Unit	2.98	2.88	3.18			2.75	3.07
Cars Available (estimate), thousands	85,178	23,321	59,628	23,278	36,778	3,243	1,302
Percent of US Total	100	27	70	27	43	4.6	1.5
Cars Per Occupied Housing Unit	1.20	1.19	1.23	1.03	1.41	1.28	1.33
Cars as Percent of Available Cars							
At 1 Car Units	39.4	44.1	36.9	43.7	32.5	37.1	32.1
Single-Family	24.0	32.9	21.5	22.7	20.8	20.4	14.9
Multi-Family	15.4	11.2	15.4	21.1	11.8	16.7	17.2
At 2 Car Units	45.6	42.2	47.3	43.0	50.2	45.9	48.0
Single-Family	35.0	34.5	36.7	31.5	39.9	34.1	35.3
Multi-Family	10.5	7.5	10.6	11.4	10.3	11.8	12.7
At 3 or More Car Units	15.1	14.0	15.8	13.3	17.3	17.0	19.9
Single-Family	13.0	12.5	13.7	11.1	15.3	14.5	16.9
Multi-Family	2.1	1.5	2.1	2.2	2.0	2.5	3.0
Cars with Parking, percent*	56-83	65-77	52-85	62-86	58-84	67-97	47-71

*Assumes each housing unit with parking has either 1 space (lower limit) or as many spaces as cars available (upper limit).

underestimate the number of cars, but to overestimate the availability of parking, since rented single-family units probably have more cars and less off-street parking than multi-family units. Third, the renter-occupied housing units found in the first step were scaled up to include owner-occupied multi-family housing units. The owner-occupied units were assumed to have the same auto availability and parking availability as specified renter-occupied units, again a conservative assumption.

The results of this expansion are shown in Table 4.2 for various geographic breakdowns, including single SMSAs which constitute major parts of the survey regions for Los Angeles and Washington. The estimate of cars available at all occupied units in Table 4.2 is about 3-1/2 percent below that reported in the Annual Housing Survey. For cars available in SMSAs, however, the underestimate is less: only 2-1/2 percent. These underestimates appear insignificant relative to other uncertainties involved in using the data.

The principal uncertainty is in the meaning of "units with parking" in Tables 4.1 and 4.2. For single-family units, the Annual Housing Survey asked whether there was a garage or carport on the property. It did not determine the availability of other off-street parking, which might be in yards or driveways. At multi-family units, the Survey determined only whether parking facilities were included in the rent. The availability of other facilities, or the nature and location of facilities included in the rent, were not reported.

The figures for units with parking in Tables 4.1 and 4.2 are thus far from definitive. They do not show yard or driveway parking which may be available at single-family units, and they do not show the number of off-street parking spaces available per unit, at either single-family or multi-family housing units. No better figures, however, were located for use in this analysis.

The lower portion of Table 4.2 shows the percentage of the total cars in each column which are at one-car, two-car, and three-car housing units. It also shows percentages at single- and multi-family housing

units, so they may be combined directly with the percentages of these types of units having off-street parking.

It is especially noteworthy in Table 4.2 that in Washington, D.C., only 54 percent of the single-family units had a garage or carport. This is much less than in Los Angeles, where 94 percent reported having a garage or carport, or in the United States as a whole, where 78 percent reported having a garage or carport. The implication is that the applicability of hybrid cars may be much less in areas like Washington than in auto-oriented regions like Los Angeles.

It is also possible that single-family units in Washington frequently provide off-street parking in yards and driveways rather than in garages or carports. Unfortunately, the Washington origin-destination survey (unlike the Los Angeles survey) did not record the availability of off-street parking at residences, and an effort to locate other relevant descriptive data was unsuccessful.

Tables 4.3 and 4.4 correlate parking and auto availability with the house value or gross rent of the housing unit. The house value (for specified owner-occupied housing) and the gross rent (for specified renter-occupied housing) are used as proxy variables for household income, with which they are positively correlated. The data source (<u>1974 Annual Housing Survey</u>) did not list parking and auto availability by household income, but the median household income is given for each house value and group rent division. These data have been taken directly from the Survey and have not been adjusted as have the data in Table 4.2.

The data show the expected result of auto availability increasing with household income. The higher the value of specified owner-occupied houses, the more likely the house has a garage or carport. The vast majority of rented units have parking includes, regardless of the monthly rent.

TABLE 4.3

PARKING AND AUTO AVAILABILITY BY VALUE OF HOUSE SPECIFIED OWNER OCCUPIED HOUSING

	House Value (dollars)							
Total U.S. Owner Households	Under $5000	$5000-$9999	$10,000-$14,999	$15,000-$19,999	$20,000-$24,999	$24,000-$34,999	$35,000 & Over	Total
Median Income (dollars)	4000	6100	8700	10,800	12,200	14,500	20,300	13,600
Units in Category (percent)	2	6	10	13	14	25	31	
Units with Garage/Carport (percent)	27	41	58	69	76	80	87	75
Automobiles Available (percent)								
No Car Households	39	45	17	10	7	5	2	8
One Car Households	46	55	53	55	62	46	33	45
Multi-Car Households	15	20	30	35	49	50	65	47
Urban Owner Households								
Inside SMSAs*								
Median Income	4200	6600	9100	11,300	12,600	14,900	20,800	14,800
Percent of Units in Category	1	4	8	11	14	27	36	
Units with Garage/Carport (percent)	25	40	57	69	77	81	87	77
Automobiles Available (percent)								
No Car Households	43	24	18	11	8	5	2	7
One Car Households	43	55	50	52	49	44	31	42
Multi-Car Households	14	21	31	37	43	51	67	51
Inside Central Cities								
Median Income	4300	6100	9100	11,300	12,400	15,200	20,600	13,500
Percent of Units in Category	1	6	12	16	16	25	24	
Units with Garage/Carport (percent)	24	40	59	69	78	84	88	75
Automobiles Available (percent)								
No Car Households	37	28	19	12	10	6	4	10
One Car Households	50	54	49	52	50	45	33	45
Multi-Car Households	13	18	31	36	40	49	63	45

*Includes households in central cities.

Source: U.S. Bureau of the Census, Annual Housing Survey 1974.

TA. . 4.4

PARKING AND AUTO AVAILABILITY BY GROSS RENT SPECIFIED RENTER OCCUPIED HOUSING

	Gross Monthly Rent (dollars)							
	No Cash Rent	Under 50	50-69	70-99	100-149	150-199	200 and Over	Total
Total U.S. Renter-Occupied Households								
Median Income, dollars	5,800	3,000	3,500	5,200	6,800	9,700	13,400	7,800
Units in Category (percent)	5	5	6	13	28	25	19	100
Units with Parking Included in Rent (percent)	--	98	98	97	96	96	92	96
Automobiles Available (percent)								
No Car Households	28	71	59	42	32	21	16	31
One Car Households	49	25	36	47	45	56	51	50
Multi-Car Households	22	4	6	10	16	23	33	19
Urban Renter-Occupied Households								
Inside SMSAs*								
Median Income, dollars	6,200	3,000	3,500	4,900	6,500	9,700	13,400	8,100
Percent of Units in Category	3	4	5	11	27	28	22	100
Units with Parking Included in Rent (percent)	--	98	98	96	96	95	92	95
Automobiles Available (percent)								
No Car Households	31	77	67	48	36	23	17	32
One Car Households	48	21	29	44	50	55	51	49
Multi-Car Households	22	2	4	8	14	22	32	19
Inside Central Cities								
Median Income, dollars	5,000	3,000	3,400	4,700	6,400	9,400	13,100	7,200
Percent of Units in Category	2	4	6	14	31	26	17	100
Units With Parking Included in Rent (percent)	--	98	98	96	96	95	90	93
Automobiles Available (percent)								
No Car Households	35	82	72	53	42	30	27	41
One Car Households	47	16	26	42	47	52	48	45
Multi-Car Households	17	1	2	6	11	18	25	14

*Includes households in central cities.

Source: U.S. Bureau of the Census, Annual Housing Survey 1974.

4.2 URBAN-BASED CARS

Table 4.5 shows the percent of cars available to households located in urban areas. The urban areas (i.e., in SMSAs) are broken down into central cities and the remainder of the counties outside the incorporated limits of the central cities. This breakout is intended to estimate urban and suburban regions. The areas outside the SMSAs may be considered rural. Approximately 3 percent of private cars are not accounted for in this table.

One-car households are about evenly distributed between urban, suburban, and rural areas, while nearly half the cars in multi-car households are located in suburban regions.

TABLE 4.5

URBAN BASED CARS

Source: U.S. Bureau of Census' Annual Housing Survey

	Urban			
	Total Inside SMSAs	Inside Central Cities	Outside Central Cities	Rural Outside SMSAs
At One-Car Households	25.8	11.8	14.0	11.9
At Multi-Car Households	44.2	15.2	29.0	15.2

The applicability of cars requiring electric recharging as of 1974 may be simply estimated from the auto and parking availability data in the above tables. Table 4.6 breaks down cars available at residences according to their location (urban or rural), their function (secondary, only, or primary car), and the type of unit at which they are parked. The table shows a range of values for each entry, corresponding to cars at units with parking available and cars at all units. Only cars are, of course, those at one-car households in Table 4.2; primary cars are the first cars at two- and three-car households; and secondary cars are all other cars.

TABLE 4.6

AVAILABILITY OF CARS BY FUNCTION, 1974

Source: U.S. Bureau of Census' Annual Housing Survey

	Percent Urban Cars*		Percent Non-Urban Cars**	
	At Single-Family Units	At Multi-Family Units	At Single-Family Units	At Multi-Family Units
Secondary Cars	22-28†	6.2-6.7††	19-26†	4.1-4.8††
Only Cars	17-22	14-15	24-33	10-11
Primary Cars	18-23	5.5-6.0	16-21	3.7-4.3

*In SMSAs

**Not in SMSAs

†First figure only includes cars at units with garage or carport. Second figure includes cars at units without garage or carport.

††First figure only includes cars at units with off-street parking included in rent. Second figure includes cars at units without off-street parking included in rent.

5 ACCIDENT RATES

Accident rates on grades and at freeway access points (frequently uphill in urban areas) are closely correlated with the speed differential between involved vehicles.[1] This section estimates accident frequency as a function of acceleration capability and percent road grade.

Gradeability has been calculated for a car with sufficient power to meet the most strenuous minimum acceleration specification (0-90 km/hr in 15 seconds) required by JPL for the hybrid vehicle. (This power is also sufficient to meet all the minimum gradeability specifications.) Figure 5.1 plots velocity versus percent grade for a typical hybrid vehicle with the specifications shown in Table 5.1.

TABLE 5.1

REFERENCE HYBRID VEHICLE SPECIFICATIONS

Test Weight	1,453 kg
Tire Friction	1%
Aerodynamic Drag-Product Area	0.75 m^2
Acceleration	0-90 km/hr in 15 seconds

Figure 5.2 indicates accident involvement rates by variation from average speed for daylight and night time operation. The probability of an accident increases when a car travels slower or significantly faster than other traffic. Traveling faster than the average traffic speed is controlled by the driver but traveling slower than traffic may be dictated by the capabilities of the vehicle.

Combining the data from Figures 5.1 and 5.2, the rate of accident involvement on various grades is calculated and shown in Fig. 5.3. The reference vehicle is capable of maintaining the 90 km/hr speed limit

[1] D. Solomon, Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle, U.S. Department of Commerce, Bureau of Public Roads, Washington, D.C., July 1964.

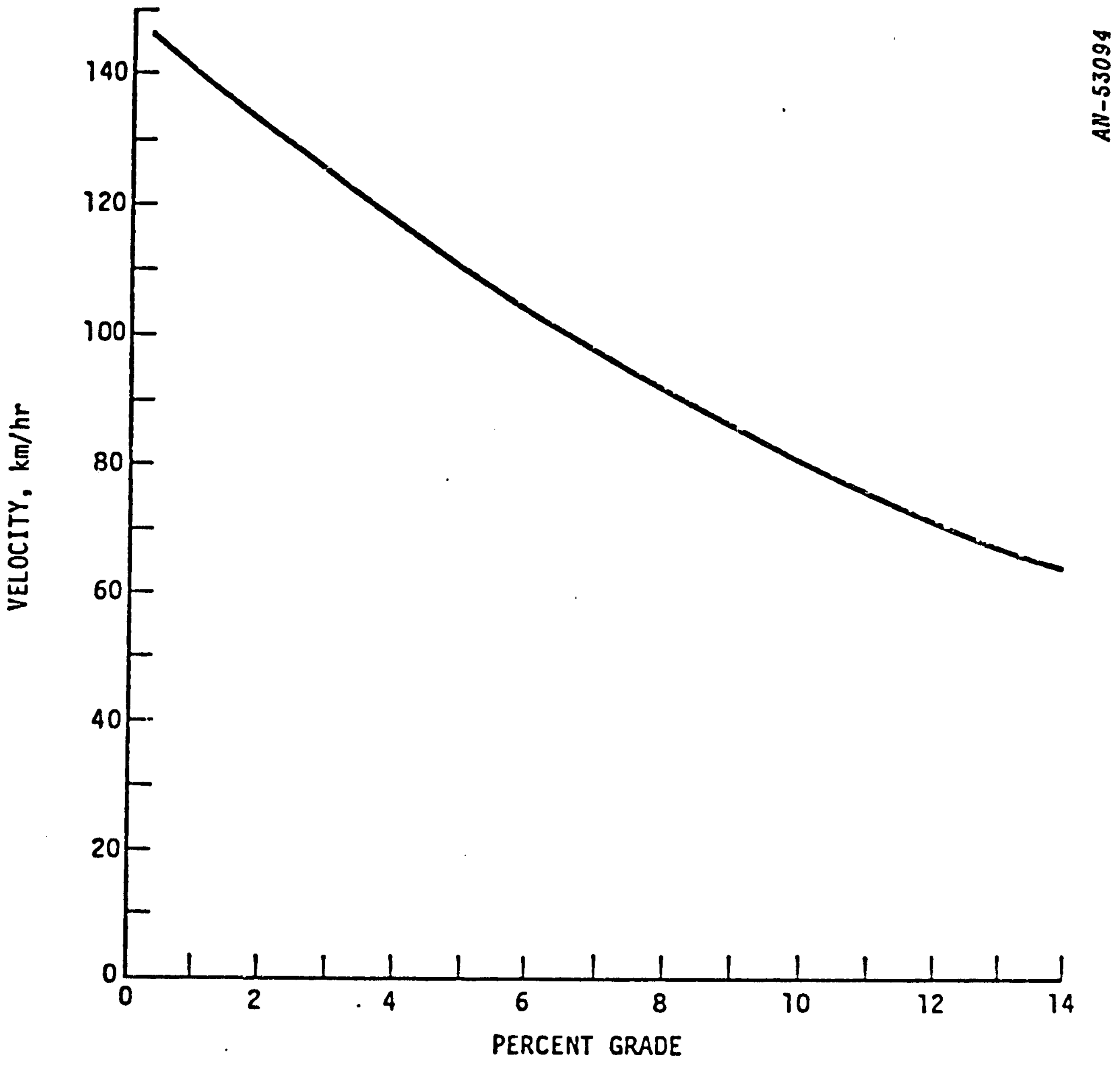
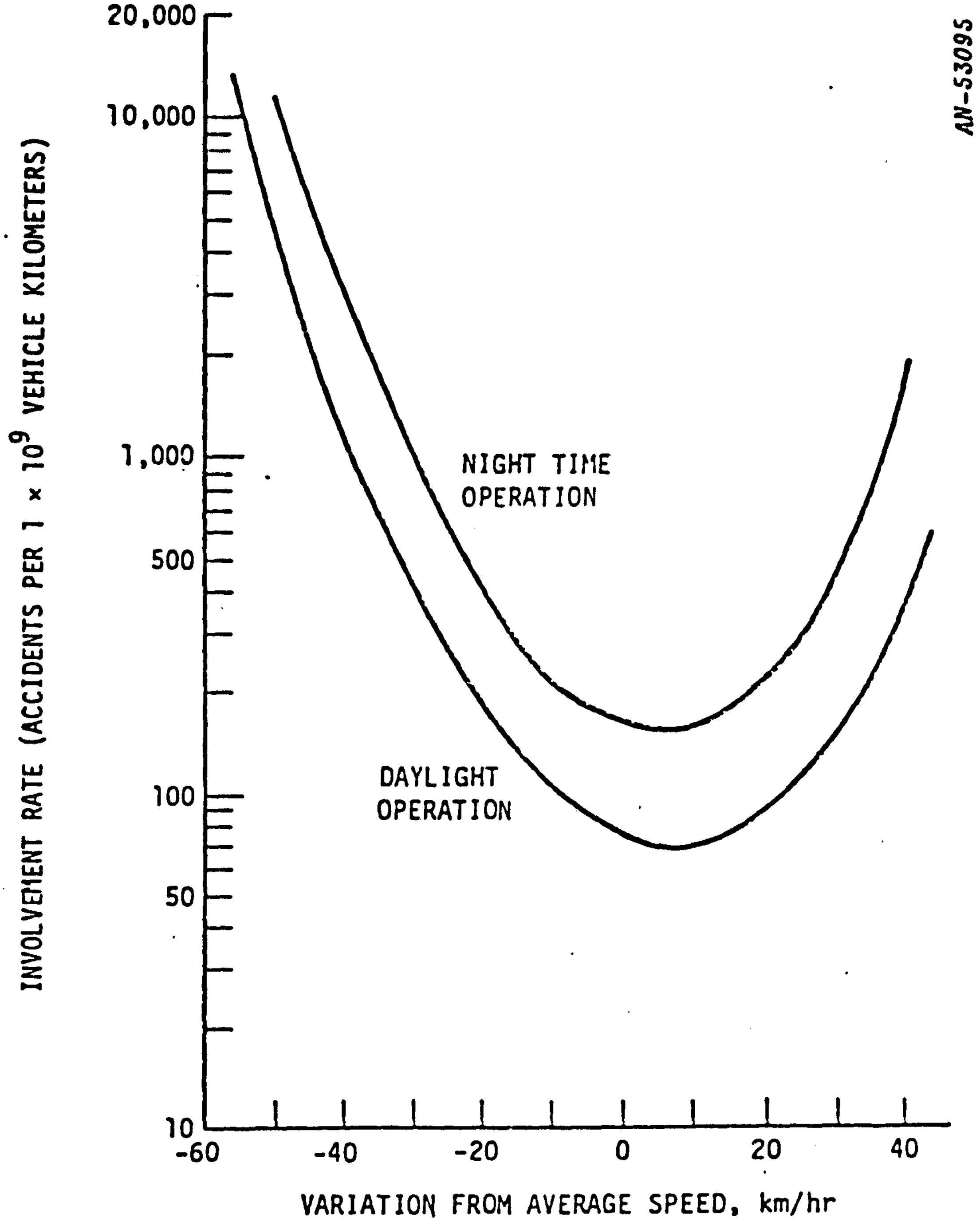


Figure 5.1. Maximum Velocity a. Percent Grade for Specified Vehicle



Source: Solomon's <u>Accidents on Main Rural Highways Related to Speed, Driver, and Vehicle</u>

Figure 5.2. Accident Involvement Rate by Variation From Average Speed

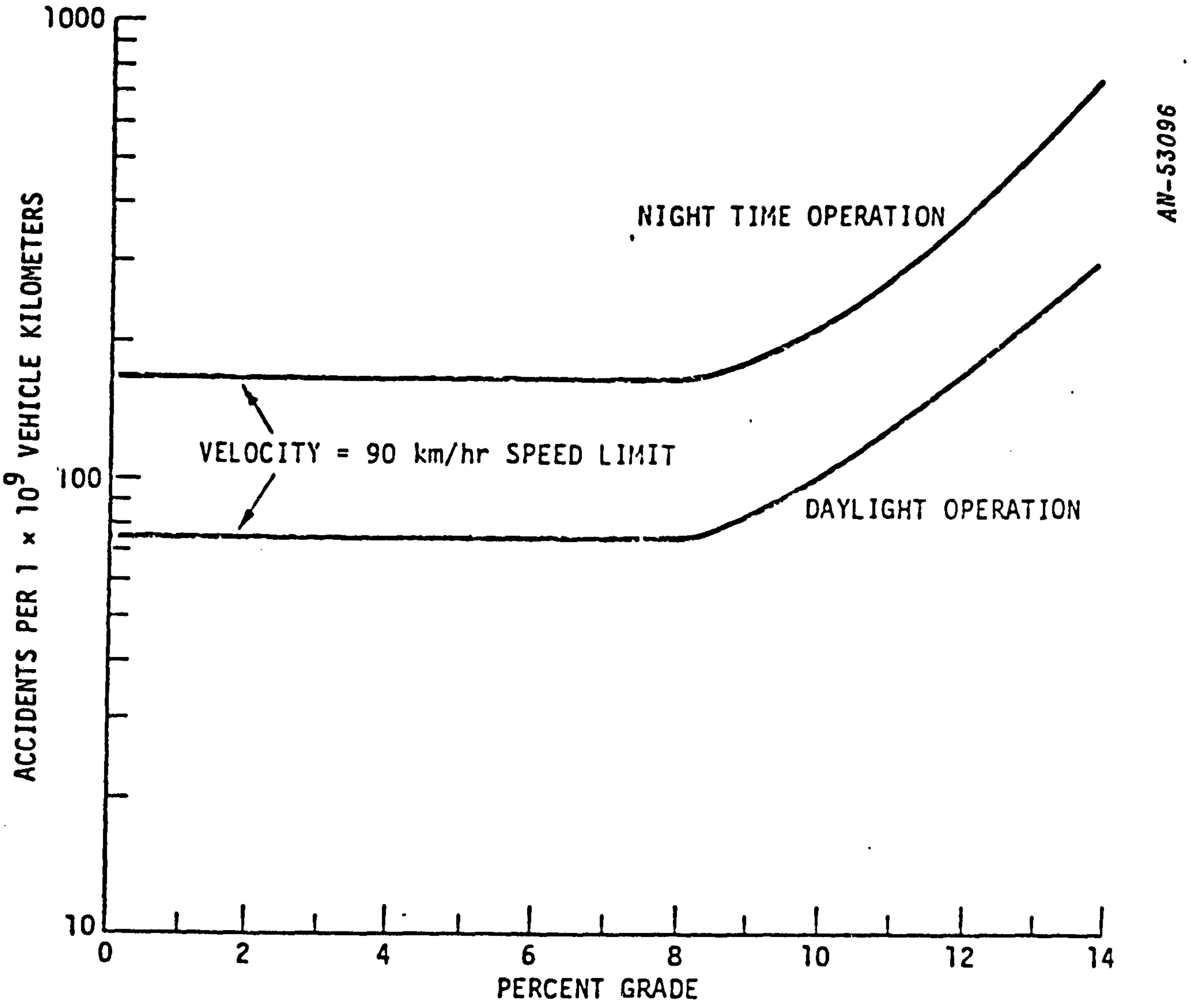


Figure 5.3. Accident Involvement Rate Versus Percent Grade for Reference Hybrid Vehicle

on all grades of 8 percent or less. Since the maximum grade allowable on Federal highways is 6 percent (on which the hybrid can do 112 km/hr) the hybrid vehicle would be able to keep up with freeway traffic. The decrease in the hybrid vehicle's top speed to below 90 km/hr would increase the probable accident rate only on grades over 8 percent, but it is unlikely that such steep roads would allow traffic speeds as fast at 90 km/hr. Therefore, on open roadways the reference hybrid vehicle would not have an accident involvement rate significantly higher than conventional vehicles.

To calculate the expected number of accidents, information is needed on the number of vehicle kilometers traveled on roads of various grades and the average traffic speed maintained.

Road grade data is not easy to obtain, however. Park and Grout[1] did make an estimate of urban and rural grades by terrain type. They estimated for the U.S. as a whole that 63.7 percent of urban highways have grades less than 3 percent, 32 percent are graded between 4 percent and 6 percent, 4 percent have a 6-9 percent grade, and 0.3 percent of the road miles are at grades greater than 9 percent. These estimates were made by comparing Geological Survey elevation maps to Federal Highway Administration data on road miles by region. This methodology does not account for such roadway constructions as switchbacks which would allow roads to be less steeply inclined than the grade of the terrain the road traverses. The data then may contain considerable errors, but no other road grade data have been located.

Even if this tenuous data were used, the expected accident rate could not be calculated since the data does not include the speed at which each grade is traveled.

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[1] B. Park, S. Grout, Road Grades - U.S. Distribution of Auto Vehicle Miles (by Region and Urban/Rural), Raytheon Service Company, Cambridge, Massachusetts, May 15, 1974.

Another safety consideration is the ability of the vehicle to attain a proper merging speed after traveling up an inclined freeway on-ramp. In California the majority of on-ramps onto elevated freeways have a 4 to 6 percent average grade and are 200 to 300 meters long. In the case of the most strenuous on-ramp (200 meters long at a 6 percent grade) the reference hybrid vehicle would be able to attain a 75 km/hr speed by the end of the on-ramp. Since 65 km/hr is considered the minimum safe merge speed,[1] the capabilities of the hybrid vehicle do not pose a safety problem when merging onto an elevated freeway.

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[1]N. Rosenberg, et al., Institutional Factors in Transportation Systems and Their Potential Bias Toward Vehicles of Particular Charateristics, Transportation Systems Center, U.S. Department of Transportation, Cambridge, Massachusetts, August 1977.

6 TAXI FLEETS

In 1977, a survey of fleets was undertaken for the Department of Energy to assess the potential for alternate technologies in light-duty highway fleets.[1] Since the questions were aimed at determining the applicability of electric vehicles for fleet use, the data on taxi fleets are helpful in assessing the usefulness of designing a hybrid vehicle to meet the requirements of taxi fleets.

The total cars in U.S. taxi fleets numbered about 336,000 in 1976. The survey included responses from 68 taxi fleets with a total of 2,071 passenger vehicles. The cars were divided into three classes based on weight. "Small" cars were all subcompacts, "medium" cars included 16 percent subcompacts and 84 percent compacts, and the "large" car class was made up of 11 percent compacts and 89 percent mid-sized and large cars.

Sixty percent of the taxis drove over 242 kilometers per day. An implicit daily distance of 251 kilometers per vehicle is derived from the average annual vehicle kilometers (91,770 km). This high daily driving distance would mean that the hybrid taxi would probably use the gasoline-powered propulsion system part of the time. Only a quarter of the vehicles sit idle at a central location for 8 hours, making battery recharging difficult for the majority of taxis.

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[1] J. Wagner, J. Naughton, and H. Brooks, Light-Duty Highway Fleets: The Potential for Alternate Technologies in Corporate Fleets and In Fleets Operated by State and Local Governments, Interim Briefing for Department of Energy, Economic Analysis Division, National Center of Energy Systems, Brookhaven National Laboratory, New York, April 1978.

TABLE 6.1

TAXI FLEETS

Total Cars in US Taxi Fleets (1976)	336,000
Cars in Taxi Fleets Sampled	2,071
Taxi Fleets Sampled	68
Average Fleet Size	30

	Car Size			
	Small	Medium	Large	Total
Weight Class, kg	Under 1,383	1,383 - 1,588	Over 1,588	
Daily Range, km				
0-80	33%	--	—	0%
81-161	—	16%	2%	5%
162-241	33%	13%	40%	35%
242 and Over	33%	71%	58%	60%
8 Hours Idle at Central Location	15%	17%	27%	25%
Not Requiring Highway Capability	--	49%	38%	40%
8 Hours Idle and No Highway	--	16%	8%	9%
Average Minimum Passenger Space	4.0	4.6	4.6	4.6

Annual Kilometers per Vehicle	91,770
Computed Replacement Age, years	2.8
Computed Replacement Kilometers	231,840

Source: Wagner et al., Light-Duty Highway Fleets

7 COMPOSITE DRIVING SCHEDULE

Table 2.2 indicates that average driving ranges for primary drivers vary from 48 km for Washington, D.C. to 78 km for Los Angeles. The standard deviation for the distributions of daily driving distances are the same magnitude as the averages. Thus, there is considerable uncertainty as to the amount of daily driving for each type of driver class and each city.

Given these uncertainties, it seems advisable to construct a composite driving schedule which allows for the differences between short trips and long trips, and between the trips taken by a 20 km/day driver and a 300 km/day driver. This is accomplished by constructing a composite driving schedule whose components are three defined schedules (SAE J227a/B, Federal Urban, and Federal Highway). However, the relative weights of each component are a function of the daily range under consideration.

The rationale for the composite driving schedule selected is as follows:

1. Most trips begin and end with low speed segments which can be characterized by the SAE J227a/B schedule (maximum speed 32 km/hr, average speed 16.5 km/hr.)

2. The majority of the average primary drivers' trips can best be characterized by the Federal Urban Driving Schedule (FUDC) which has a top speed of about 92 km/hr and an average speed of 31 km/hr.

3. Most drivers whose daily range exceeds the average ranges utilize highways or freeways to a greater extent than do others. This additional driving can best be characterized by the Federal Highway Driving Schedule (FHDC), which has a maximum speed of 95 km/hr and an average speed of about 77 km/hr.

The choice of the number of J227a/B schedules is somewhat arbitrary as little is known about the beginning and ending of most trips. However, we have selected six cycles as the maximum to be included in the composite schedule. Six cycles is about 2 kilometers.

The FUDC covers about 12 kilometers. Thus, three FUDC cycles and six J227a/B cycles give a total range of about 38 kilometers, which falls in the region of interest.

Additional driving is assumed to consist of Federal Highway cycles.

In most applications, the range of interest will not correspond to an integral number of J227a/B, FUDC, and FHDC cycles. However, the energy (fuel and electricity) comsumption can be readily calculated by using partial cycles.

In summary, the composite driving schedule is as follows:

1. For a daily range of up to six times the J227a/B cycle length, J227a/B cycles are used exclusively.

2. For a daily range greater than the maximum for (1), but less than the sum of six J227A/B cycles and three FUD cycles, the urban cycles are used (plus the six J227a/B cycles).

3. Beyond the maximum range allowed by (2), Federal Highway cycles are added to get the desired range.

This approach has the advantage for parametric studies that there will not be discontinuities in energy use as driving range increases.

APPENDIX

CALCULATION OF MEAN AND VARIANCE DIRECTLY FROM TABULAR CUMULATIVE DISTRIBUTIONS

Often random variables are described by a tabular presentation of their cumulative probability distribution. Usually the analytical representation of the probability density function for these variables does not exist or is not known. Thus, direct calculation of the mean and variance from Eqs. 1 and 2 is not practical:

$$\mu = \int_{-\infty}^{\infty} x p(x) dx \qquad \text{A1.1}$$

$$\sigma^2 = \int_{-\infty}^{\infty} (x - \mu)^2 \, p(x) dx \qquad \text{A1.2}$$

where

μ = mean of x

$p(x)$ = probability density function

σ^2 = variance of x

The following approach allows μ and σ^2 to be calculated directly from the tabular cumulative distribution. Integration of Eq. 1 by parts yields[1]

$$\mu = x\,P(x) \Big|_{-\infty}^{\infty} - \int_{-\infty}^{\infty} P(x) dx \qquad \text{A1.3}$$

where

$$P(x) = \int_{-\infty}^{x} p(u) du$$

If $P(x) = 1 - Q(x)$ is substituted into Eq.A1.3 and the lower limit is zero rather than $-\infty$ (as is true for driving distance), we get

[1] F.A. Haight, Mathematical Theories of Traffic Flow, Academic Press, 1963, p. 22.

$$\mu = x[1 - Q(x)]\Big|_0^\infty - \int_0^\infty [1 - Q(x)]dx = \int_0^\infty Q(x)dx \qquad \text{A1.4}$$

since lim $xQ(x) = 0$ as $x \to \infty$.

Using the same approach, it is straightforward to show that

$$\sigma^2 = \int_0^\infty x^2 Q(x)dx - \mu^2 \qquad \text{A1.5}$$

Since we are working with tabular data, Eqs. A.4 and A.5 must be rewritten as

$$\mu = \sum_{i=1}^{N} \left[1 - \frac{\left(P_i - P_{i-1}\right)}{2}\right](x_i - x_{i-1}) \qquad \text{A1.6}$$

and

$$\sigma^2 = \sum \left[1 - \frac{\left(P_i - P_{i-1}\right)}{2}\right] x_i^2 (x_i - x_{i-1}) - \mu^2 \qquad \text{A1.7}$$

where

P_i = value of cumulative distribution for range of x_i

$P_0 = 0$

$x_0 = 0$

$P_N = 1$

	House Value (dollars)							
Total U.S. Owner Households	Under $5000	$5000-$9999	$10,000-$14,999	$15,000-$19,999	$20,000-$24,999	$24,000-$34,999	$35,000 & Over	Total
Median Income (dollars)	4000	6100	8700	10,800	12,200	14,500	20,300	13,600
Units in Category (percent)	2	6	10	13	14	25	31	
Units with Garage/Carport (percent)	27	41	58	69	76	80	87	75
Automobiles Available (percent)								
No Car Households	39	45	17	10	7	5	2	8
One Car Households	46	55	53	55	62	46	33	45
Multi-Car Households	15	20	30	35	49	50	65	47
Urban Owner Households								
Inside SMSAs*								
Median Income	4200	6600	9100	11,300	12,600	14,900	20,800	14,800
Percent of Units in Category	1	4	8	11	14	27	36	
Units with Garage/Carport (percent)	25	40	57	69	77	81	87	77
Automobiles Available (percent)								
No Car Households	43	24	18	11	8	5	2	7
One Car Households	43	55	50	52	49	44	31	42
Multi-Car Households	14	21	31	37	43	51	67	51
Inside Central Cities								
Median Income	4300	6100	9100	11,300	12,400	15,200	20,600	13,500
Percent of Units in Category	1	6	12	16	16	25	24	
Units with Garage/Carport (percent)	24	40	58	69	78	84	88	75
Automobiles Available (percent)								
No Car Households	37	28	19	12	10	6	4	10
One Car Households	50	54	49	52	50	45	33	45
Multi-Car Households	13	18	31	36	40	49	63	45

*Includes households in central cities.

	Gross Monthly Rent (dollars)							
Total U.S. Renter-Occupied Households	No Cash Rent	Under 50	50-69	70-99	100-149	150-199	200 and Over	Total
Median Income, dollars	5,800	3,000	3,500	5,200	6,800	9,700	13,400	7,800
Units in Category (percent)	5	5	6	13	28	25	19	100
Units with Parking Included in Rent (percent)	--	98	98	97	96	96	92	96
Automobiles Available (percent)								
No Car Households	28	71	59	42	32	21	16	31
One Car Households	49	25	36	47	45	56	51	50
Multi-Car Households	22	4	6	10	16	23	33	19
Urban Renter-Occupied Households								
Inside SMSAs*								
Median Income, dollars	6,200	3,000	3,500	4,900	6,500	9,700	13,400	8,100
Percent of Units in Category	3	4	5	11	27	28	22	100
Units with Parking Included in Rent (percent)	--	98	98	96	96	95	92	95
Automobiles Available (percent)								
No Car Households	31	77	67	48	36	23	17	32
One Car Households	48	21	29	44	50	55	51	49
Multi-Car Households	22	2	4	8	14	22	32	19
Inside Central Cities								
Median Income, dollars	5,000	3,000	3,400	4,700	6,400	9,400	13,100	7,200
Percent of Units in Category	2	4	6	14	31	26	17	100
Units With Parking Included in Rent (percent)	--	98	98	96	96	95	90	93
Automobiles Available (percent)								
No Car Households	35	82	72	53	42	30	27	41
One Car Households	47	16	26	42	47	52	48	45
Multi-Car Households	17	1	2	6	11	18	25	14

*Includes households in central cities.

Source: U.S. Bureau of the Census, Annual Housing Survey 1974.

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1/23/79

AVERAGE TRIP SPEED

In calculating the average speed a passenger car attains during trips, GRC has generally followed the methodology used by the EPA in determining "composite" fuel economy. That is, urban travel is defined as stop-start driving over a combination of surface streets and freeways; rural travel is free-moving highway driving; and the composite is a weighted average of the two.

The 1974 Highway Statistics[1] splits total vehicle miles into 55 percent urban and 45 percent rural driving.

Most speed data report free-moving speeds. To estimate the average trip speed in urban stop-start driving, data on the median trip distance and median trip time for home-to-work auto trips were used. The average trip speed for 40 cities surveyed[2] was 36.6 km/hr. The 1974 Highway Statistics shows the average free-moving speed on main rural highways to be 89.8 km/hr.

Combining the average urban and rural trip speeds yields an average trip speed of 50 km/hr for all travel.

Urban Travel	55%
Average Trip Speed in Urban Home-to-Work Auto Travel	36.6 km/hr
Time to Travel 55 km	1.50 hrs
Rural Travel	45%
Average Free-Moving Speed on Main Rural Highways	89.8 km/hr
Time to Travel 45 km	0.50 hrs
Average Trip Speed, All Travel	
$\frac{100\ \text{km}}{2.00\ \text{hrs}}$ =	50 km/hr

REFERENCES

1. Highway Statistics, U.S. Department of Transportation, Federal Highway Administration, Washington, D.C., 1974.

2. Selected Characteristics of Travel to Work in 20 Metropolitan Areas: 1975 and 1976, U.S. Department of Commerce, Bureau of the Census, Series P-23, No. 68, February 1978 and Series P-23, No. 72, September 1978.

APPENDIX A2

WEIGHT AND MANUFACTURING

COST ESTIMATION PROGRAM

(WANDC)

WANDC - GENERAL DESCRIPTION

Using the equations listed in Section II, WANDC computes component weights and costs and power requirements for hybrid vehicles. Power-weight, power-cost, and weight-cost influence coefficients, and minimum weights and costs for components (derived from references, Section III) are input for each case and computations made with user specified heat engine power fraction(s) and battery weight fraction(s).

Printed output includes input specs; calculated weight and cost of purposed vehicle and its carriage, heat engine, electric motor, transaxle and batteries; rated power for the heat engine and electric motor; and battery specific power. An error message flags cases where battery power exceeds the maximum available.

Plotting of vehicle weight, vehicle cost, battery weight, and battery specific power versus battery weight fraction for each heat engine power fraction is optional.

POWER-WEIGHT RELATIONSHIPS

1) BASIC

1.1 $$\frac{P_{HE} + P_{T}}{W_V + W_{PL}} = R_p^{\circ} + k_p \overline{P_{HE}}$$

1.2 $$W_E = W_E^{\circ} + \epsilon\left(W_{HE} + W_m + W_T + W_E + W_{FLMRY}\right)$$

1.3 $$W_V = W_E + W_{HE} + W_m + W_T + W_E$$

1.4 a) $$W_{HE} = W_{HE}^{\circ} + k_{HE} P_{HE}$$

b) $$W_m = W_m^{\circ} + k_m P_m = W_m^{\circ} + k_m \left(\frac{1 - \overline{P_{HE}}}{\overline{P_{HE}}}\right) P_{HE}$$

c) $$W_T = W_T^{\circ} + k_T (P_{HE} + P_m)$$

d) $$W_E = \overline{W_E} \cdot W_V$$

1.5 $$P_m = P_{HE} \left(\frac{1 - \overline{P_{HE}}}{\overline{P_{HE}}}\right)$$

1.6 $$P_{ES} = P_n (1000./.8)/W_B$$

2) DERIVED

2.1 $$W_V = W_E^{\circ} + (1+\theta)(W_{HE} + W_m + W_T + W_B)$$

$$= W_E^{\circ} + (1+\theta)(W_{HE} + W_m + W_T + \overline{W_E} \cdot W_V)$$

2.2 $$W_V = \frac{1}{1 - (1+\theta)\overline{W_E}} \left[W_c^{\circ} + (1+\theta)(W_{HE} + W_m + W_T)\right]$$

2.3 $$W_V = \frac{1}{1 - (1+\theta)\overline{W_E}} \left[W_c^{\circ} + (1+\theta)\left(W_{HE}^{\circ} + W_m^{\circ} + W_T^{\circ} + \left(k_{HE} + k_T + \left(\frac{1 - \overline{P_{HE}}}{\overline{P_{HE}}}\right) k_T + \ldots\right.\right.\right.$$ [illegible]

2.4 $$P_{HE} = \frac{(R_p^{\circ} + k_p \overline{P_{HE}})(W_V + W_{PL})}{1 + \left(\frac{1 - \overline{P_{HE}}}{\overline{P_{HE}}}\right)} = \overline{P_{HE}} (R_p^{\circ} + k_p \overline{P_{HE}})(W_V + W_{PL})$$

2.5 $$\omega_r \left[1 - \frac{1}{1-(1+\theta)\overline{WE}}\,(1+\theta)\left(k_{PE} + k_T + \left(\frac{1-\overline{PE}}{\overline{PE}}\right)(k_T + k_m)\right)\overline{PE}\,\left(k_f^{\circ} + k_f\,\overline{PE}\right)\right]$$

$$= \frac{1}{1-(1+\theta)\overline{WE}}\left(\omega_c^{0} + (1+\theta)\left(\omega_{PE}^{0} + \omega_m^{0} + \omega_T^{0}\right)\right)$$

2.6 $$\omega_r = \frac{\dfrac{1}{1-(1+\theta)\overline{WE}}\left(\omega_c^{0} + (1+\theta)\left(\omega_{PE}^{0} - \omega_m^{0} + \omega_T^{0}\right)\right)}{1 - \dfrac{(1+\theta)\overline{PE}\,\left(k_f^{\circ} + k_f\,\overline{PE}\right)}{1-(1+\theta)\overline{WE}}\left[k_{PE} + k_T + \left(\dfrac{1-\overline{PE}}{\overline{PE}}\right)(k_T + k_m)\right]}$$

1) [illegible]

1.1 $C_c = C_c^o + CK_c\, W_c$

1.2 $C_{HE} = C_{HE}^o + CK_{HE}\, P_{HE}$

1.3 $C_m = C_m^o + CK_m\, P_m$

1.4 $C_T = C_{TF}^o + CK_{TA}\, (P_{HE} + P_m)$ OR $C_T = C_{Tm}^o + C_{\ldots}$

Automatic [illegible]

1.5 $C_B = CK_E\, W_E'$

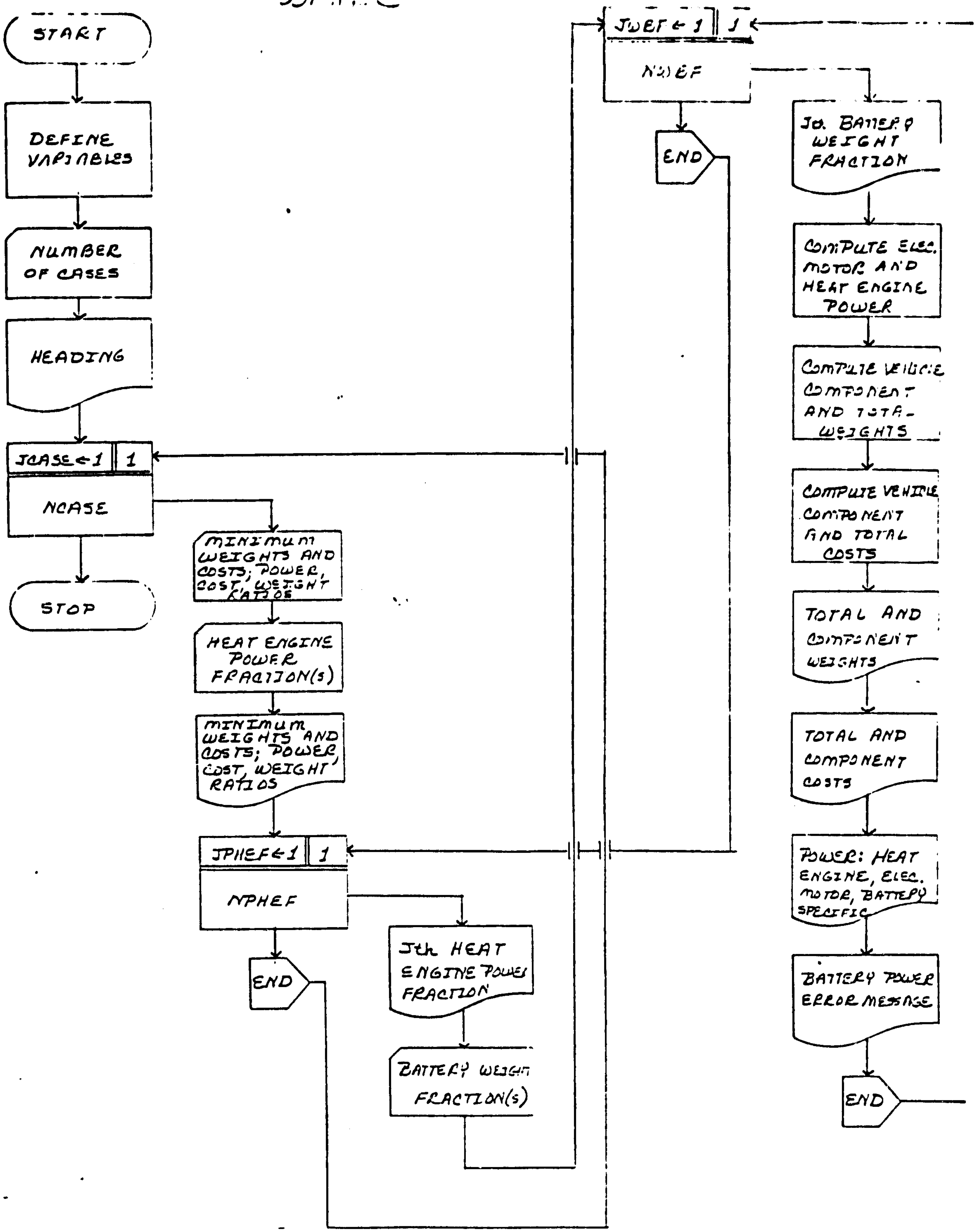
1.6 $C_V = C_c + C_{HE} + C_m + C_T + C_B$

OF POOR QUALITY

EQUATIONS	FORTRAN	UNITS	COMMENTS
W_V	WV	KG	Vehicle Weight
W_T	WT	KG	Transaxle Weight
W_B	WB	KG	Battery Weight
W_C	WC	KG	Carriage Weight
W_{HE}	WHE	KG	Heat Engine Weight
W_m	WM	KG	Electric Motor Weight
W_{PL}	WPL	KG	Payload Weight
W_{PLMAX}	WPLMAX	KG	Maximum Payload Weight
W_T^0	WTZ	KG	Transaxle Weight (Minimum)
W_C^0	WCZ	KG	Carriage Weight (Minimum)
W_{HE}^0	WHEZ	KG	Heat Engine Weight (Minimum)
W_m^0	WMZ	KG	Electric Motor Weight (Minimum)
P_{BS}	PBF	KW	Battery Specific Power
P_{HE}	PHE	KW	Heat Engine Power
P_m	PM	KW	Electric Motor Power
$\overline{P_{HE}}$	PHEF		Heat Engine Power Fraction
$\overline{W_B}$	WBF		Battery Weight Fraction
R_P^0	KPZ	KW/KG	Rated power (Minimum)
k_{HE}	EKHE	KG/KW	Heat engine weight coefficient
k_m	EKM	KG/KW	Electric motor weight coefficient
k_P	EKP	KW/KG	Power coefficient
k_T	EKT	KG/KW	Transaxle weight coefficient
θ	THETA	Radians	
C_V	CV	$	Vehicle cost
C_B	CB	$	Battery cost
C_C	CC	$	Carriage cost
C_{HE}	CHE	$	Heat Engine cost
C_m	CM	$	Electric Motor cost
C_T	CT	$	Transaxle cost
C_C^0	CCZ	$	Carriage Cost (Minimum)
C_{HE}^0	CHEZ	$	Heat Engine Cost (Minimum)
C_m^0	CMZ	$	Motor Cost (Minimum)
C_{TA}^0	CTAZ	$	Transaxle (automatic) Cost (Minimum)
C_{TM}^0	CTMZ	$	Transaxle (manual) Cost (Minimum)
CK_B	CKB	$/KG	Battery Cost Coefficient
CK_C	CKC	$/KG	Carriage Cost Coefficient
CK_{HE}	CKHE	$/KW	Heat Engine Cost Coefficient
CK_m	CKM	$/KW	Electric Motor Cost Coefficient
CK_{TA}	CKTA	$/KW	Transaxle (automatic) cost coefficient
CK_{TM}	CKTM	$/KW	Transaxle (manual) cost coefficient

[illegible]
[illegible] [illegible]

EQUATIONS	PROGRAM	UNITS	COMMENTS
—	PEFMX	KW/KG	Maximum Battery Power
—	PBO	KW	Battery Output


START
DEFINE VARIABLES
NUMBER OF CASES
HEADING
JCASE ← 1
1
NCASE
STOP
MINIMUM WEIGHTS AND COSTS; POWER, COST, WEIGHT RATIOS
HEAT ENGINE POWER FRACTION(s)
MINIMUM WEIGHTS AND COSTS; POWER, COST, WEIGHT RATIOS
JPHEF ← 1
1
NPHEF
END
Jth HEAT ENGINE POWER FRACTION
BATTERY WEIGHT FRACTION(s)
JWEF ← 1
1
NWEF
END
Jth BATTERY WEIGHT FRACTION
COMPUTE ELEC. MOTOR AND HEAT ENGINE POWER
COMPUTE VEHICLE COMPONENT AND TOTAL WEIGHTS
COMPUTE VEHICLE COMPONENT AND TOTAL COSTS
TOTAL AND COMPONENT WEIGHTS
TOTAL AND COMPONENT COSTS
POWER: HEAT ENGINE, ELEC. MOTOR, BATTERY SPECIFIC
BATTERY POWER ERROR MESSAGE
END

APPENDIX A2

PROGRAM LISTING

```
                PROGRAM WANDC
0003            REAL PHEF(20),WBF(22)
0  3            REAL PWV(22),PCV(22),PWB(22),PPBF(22)
0               READ 400,NPLOT
0011            READ 400, NCASE
          C
          C     CASE LOOP
          C
0017            DO 350 JCASE=1,NCASE
0021            READ 400, KIND
0026            READ 410,WCZ,WHEZ,WMZ,WTZ,WPL,WPLMX,THETA
0050            READ 410,RPZ,EKP,EKHE,EKM,EKT
0066            READ 410,CCZ,CHEZ,CMZ,CTAZ,CTMZ
0104            READ 410,CKC,CKHE,CKM,CKTA,CKTM,CKB
0124            READ 410,PBFMX
0132            READ 400,NPHEF
0140            READ 410,(PHEF(J), J=1,NPHEF)
          C
          C     PRINT HEADING
          C
1153            PRINT 500
1157            PRINT 510
1163            PRINT 520,WCZ,WHEZ,WMZ,WTZ,WPL,WPLMX
1203            PRINT 530
1207            PRINT 520,CCZ,CHEZ,CMZ,CTAZ,CTMZ
1225            PRINT 540
1231            PRINT 520,CKHE,CKM,CKTA,CKTM
  5             PRINT 550
                PRINT 520,CKC,CKB
1261            PRINT 560
1265            PRINT 520,RPZ,EKP,EKHE,EKM,EKT
1303            PRINT 565,THETA
1311            PRINT 570,PBFMX
          C
          C     HEAT ENGINE FRACTION LOOP
          C
 317            DO 340 JPHEF=1,NPHEF
 321            PRINT 575
 324            PRINT 580,PHEF(JPHEF)
 332            READ 400,NWBF
 340            READ 410,(WBF(J),J=1,NWBF)
          C
          C     BATTERY WEIGHT FRACTION LOOP
          C
 353            DO 330 JWBF=1,NWBF
          C
          C     COMPUTATIONS
          C
 355            PRINT 585,WBF(JWBF)
 362            EOPT=1+THETA
 364            EPHEF=(1-PHEF(JPHEF))/PHEF(JPHEF)
 370            WPR=EOPT*PHEF(JPHEF)*(RPZ+EKP*PHEF(JPHEF))/(1-EOPT     EKH
               1E+EKT+EPHEF*(EKT+EKM))
                WV=((WCZ+THETA*WPLMX+EOPT*(WHEZ+WMZ+WTZ))/(1-EOPT*-    R*
               1WPL)/(1-WPR)
```

```
32         PHE=PHEF(JPHEF)*(WV+WPL)*(RPZ+EKP*PHEF(JPHEF))
           PM=PHE*EPHEF
           PBO=PM*1000/.8
46         WB=WBF(JWBF)*WV
50         IF(PBFMX.NE.0.)PBF=PBO/WB
54         WT=WTZ+EKT*(PHE+PM)
60         WM=WMZ+EKM*PM
63         WHE=WHEZ+EKHE*PHE
66         WC=WCZ+THETA*(WHE+WM+WT+WB+WPLMX)
75         CC=CCZ+CKC*WC
00         CHE=CHEZ+CKHE*PHE
03         CM=CMZ+CKM*PM
06         CT=CTAZ+CKTA*(PHE+PM)
11         IF(KIND.GT.1)CT=CTMZ+CKTM*(PHE+PM)
20         CB=CKB*WB
22         CV=CC+CHE+CM+CT+CB
      C
      C    PRINT OUTPUT
      C
27         PRINT 590
33         PRINT 520,WV,WC,WHE,WM,WT,WB
53         PRINT 600
57         PRINT 520,CV,CC,CHE,CM,CT,CB
77         PRINT 610
03         PRINT 520,PHE,PM,PBF
15         PRINT 620,CV
           IF(PBF.GT.PBFMX)PRINT 630
           PWV(JWBF)=WV
33         PCV(JWBF)=CV
35         PWB(JWBF)=WB
36         PPBF(JWBF)=PBF
40     330 CONTINUE
42         IF(NPLOT.EQ.0)GO TO 340
43         CALL PLOTS
44         CALL SCALE(WBF,10.,NWBF,1)
47         PWV(NWBF+1)=0.0
51         PCV(NWBF+1)=0.0
52         PWB(NWBF+1)=0.0
53         PPBF(NWBF+1)=0.0
54         PWV(NWBF+2)=500.0
55         PCV(NWBF+2)=1000.0
57         PWB(NWBF+2)=100.0
60         PPBF(NWBF+2)=60.0
62         CALL AXIS(0.,0.,23HBATTERY WEIGHT FRACTION,23,10.,0.,WBF(NWBF+1),W
          1BF(NWBF+2),0)
75         CALL AXIS(0.,0.,14HVEHICLE WEIGHT,14,10.,90.,PWV(NWBF+1),PWV(NWBF+
          12),0)
11         CALL AXIS(-.5,0.,12HVEHICLE COST,12,10.,90.,PCV(NWBF+1),PCV(NWBF+2
          1),0)
25         CALL AXIS(-1.,0.,14HBATTERY WEIGHT,14,10.,90.,PWB(NWBF+1),PWB(NWBF
          1+2),0)
41         CALL AXIS(-1.5,0.,22HBATTERY SPECIFIC POWER,22,10.,90.,PPBF(NWBF+1
          1),PPBF(NWBF+2),0)
55         CALL LINE(WBF,PWV,NWBF,1,1,1)
61         CALL LINE(WBF,PCV,NWBF,1,1,2)
```

```
5          CALL LINE(WBF,PWB,NWBF,1,1,3)
           CALL LINE(WBF,PPBF,NWBF,1,1,12)
-          CALL NUMBER(8.5,9.,0.135,PHEF(JPHEF),0.,12H5HPHEF=,E8.2)
3          CALL PLOT(13.,0.,-3)
6      340 CONTINUE
1      350 CONTINUE
3          STOP
5      400 FORMAT(I10)
5      410 FORMAT(7F10.4)
5      500 FORMAT(1H1,*VEHICLE WEIGHTS, COSTS, AND POWER RATINGS*)
5      510 FORMAT(1H-,*BASELINE VALUES*/2X,*WEIGHTS*/7X,*CARRIAGE*,6X,*HEAT E
          1NGINE*,5X,*ELEC. MOTOR*,6X,*TRANSAXLE*,8X,*PAYLOAD*,7X,*MAX PAYLOA
          1D*)
5      520 FORMAT(1H ,8E16.6)
5      530 FORMAT(1H ,1X,*COSTS*/7X,*CARRIAGE*,6X,*HEAT ENGINE*,5X,*ELEC. MOT
          1OR*,6X,*TRANS/AUTO*,6X,*TRANS/MAN*)
5      540 FORMAT(1H0,*COEFFICIENTS*/2X,*POWER/COST RELATIONSHIPS*/5X,*HEAT E
          1NGINE*,5X,*ELEC. MOTOR*,6X,*TRANS/AUTO*,6X,*TRANS/MAN*)
5      550 FORMAT(1H ,1X,*WEIGHT/COST RELATIONSHIPS*/7X,*CARRIAGE*,7X,*BATTER
          1IES*)
5      560 FORMAT(1H ,1X,*POWER/WEIGHT RELATIONSHIPS*/15X,*OVERALL*,15X,*HEAT
          1 ENGINE*,5X,*ELEC. MOTOR*,6X,*TRANSAXLE*)
5      565 FORMAT(1H0,*WEIGHT PROPAGATION FACTOR = *,E12.6)
5      570 FORMAT(1H ,*BATTERY POWER FRACTION (MAXIMUM) =*,E16.6)
5      575 FORMAT(1H-,132(1H*))
5      580 FORMAT(1H0,*HEAT ENGINE POWER FRACTION =*,E12.6)
-      585 FORMAT(1H0,*BATTERY WEIGHT FRACTION =*,E12.6)
-      590 FORMAT(1H ,*WEIGHTS*/7X,*VEHICLE*,09X,*CARRIAGE*,6X,*HEAT ENGINE*,
          15X,*ELEC. MOTOR*,6X,*TRANSAXLE*,7X,*BATTERIES*)
5      600 FORMAT(1H ,*COST*/7X,*VEHICLE*,9X,*CARRIAGE*,6X,*HEAT ENGINE*,5X,*
          1ELEC. MOTOR*,6X,*TRANSAXLE*,7X,*BATTERIES*)
5      610 FORMAT(1H ,*RATED POWER*/5X,*HEAT ENGINE*,6X,*ELEC. MOTOR*,6X,*BAT
          1TERY*)
5      620 FORMAT(1H0,*TOTAL ESTIMATED VEHICLE COST =*,E16.6)
5      630 FORMAT(1H ,39H*****BATTERY POWER EXCEEDS MAXIMUM*****)
5          END
```

APPENDIX A2

TYPICAL PROGRAM OUTPUT

```
VEHICLE WEIGHTS, COSTS, AND POWER RATINGS


BASELINE VALUES
 WEIGHTS
      CARRIAGE       HEAT ENGINE      ELEC. MOTOR      TRANSAXLE        PAYLOAD          MAX PAYLOAD
    1.130000E+03    7.700000E+01     1.850000E+01     3.100000E+01     1.400000E+02     5.430000E+02
 COSTS
      CARRIAGE       HEAT ENGINE      ELEC. MOTOR      TRANS/AUTO       TRANS/MAN
   -4.642500E+02    1.592500E+02     4.400000E+02     1.604800E+02     1.543500E+02

COEFFICIENTS
 POWER/COST RELATIONSHIPS
     HEAT ENGINE     ELEC. MOTOR       TRANS/AUTO       TRANS/MAN
    5.260000E+00    2.140000E+03     9.800000E-02     3.830000E-02
 WEIGHT/COST RELATIONSHIPS
      CARRIAGE        BATTERIES
    2.390000E+00    2.000000E+00
 POWER/WEIGHT RELATIONSHIPS
               OVERALL                        HEAT ENGINE      ELEC. MOTOR      TRANSAXLE
    2.750000E-02    1.090000E-02     2.190000E+00     1.750000E+00     1.125000E+00

WEIGHT PROPAGATION FACTOR = 2.000000E-01
BATTERY POWER FRACTION (MAXIMUM) =     1.000000E+02


***********************************************************************************************************************

HEAT ENGINE POWER FRACTION =3.000000E-01

BATTERY WEIGHT FRACTION =1.000000E-01
WEIGHTS
      VEHICLE         CARRIAGE       HEAT ENGINE      ELEC. MOTOR      TRANSAXLE        BATTERIES
    1.789335E+03    1.305389E+03     1.160332E+02     9.122291E+01     9.778635E+01     1.789335E+02
COST
      VEHICLE         CARRIAGE       HEAT ENGINE      ELEC. MOTOR      TRANSAXLE        BATTERIES
    4.021734E+03    2.715630E+03     2.529290E+02     5.290097E+02     1.642978E+02     3.578670E+02
RATED POWER
     HEAT ENGINE     ELEC. MOTOR       BATTERY
    1.780989E+01    4.155555E+01     2.993030E+02

TOTAL ESTIMATED VEHICLE COST =     4.021734E+03
*****BATTERY POWER EXCEEDS MAXIMUM*****

BATTERY WEIGHT FRACTION =1.200000E-01
WEIGHTS
      VEHICLE         CARRIAGE       HEAT ENGINE      ELEC. MOTOR      TRANSAXLE        BATTERIES
    1.846981E+03    1.314997E+03     1.171585E+02     9.339576E+01     9.978182E+01     2.216377E+02
COST
      VEHICLE         CARRIAGE       HEAT ENGINE      ELEC. MOTOR      TRANSAXLE        BATTERIES
    4.135734E+03    2.738352E+03     2.557283E+02     5.315668E+02     1.664717E+02     4.432753E+02
RATED POWER
     HEAT ENGINE     ELEC. MOTOR       BATTERY
    1.834182E+01    4.279757E+01     2.413713E+02

TOTAL ESTIMATED VEHICLE COST =     4.135734E+03
*****BATTERY POWER EXCEEDS MAXIMUM*****
```

REFERENCES - APPENDIX A2

1. Estimated Weights and Manufacturing Costs of Automobiles, Robert G. Fitzgibbons et al., Rath & Strong, Inc. Prepared for DOT/TSC Contract No. DOT-TSC-1067, Task 1

2. Near Term Electric Vehicle Program, "Phase I - Final Report," Corporate Research and Development, General Electric Company, prepared for ERDA Contract No. EY-76-C-03-1294.

APPENDIX A3

LIFE CYCLE COST PROGRAM

(LYFECC)

BACKGROUND

In developing a life cycle cost estimation program that would accurately reflect the time span relevant (1985-1995) to our study, the same general methodology as that used in Reference 2, in conjunction with the guidelines provided in Reference 1, were used.

In the area of operating costs, maintenance, repair, and fuel costs were computed on a cents per kilometer basis, the results being multiplied by the number of kilometers travelled in each year. In addition, repair costs were adjusted by a repair kilomage factor to reflect the dependency between repair cost and vehicle usage. Fuel and electricity prices were projected for each year based on Table B-1 of Reference 1.

Average annual vehicle kilometers travelled (VKT) were estimated by adjusting "VKT versus age of vehicle" (Table C-3, Reference 1) by the forecast for VKT for passenger cars in the USA given in the same reference.

Financing of both vehicle and replacement batteries is at 12% interest rate, with a 30% down payment. The vehicle is financed over four years, the battery replacement sets over three. Battery replacement is a function of battery life expectancy, computed in kilometers and, therefore, is directly dependent on vehicle usage. The assumption is made that, when battery replacement is required in the last year (i.e., 199 that the vehicle will be 'junked' when battery life ceases. Whatever 'life' batteries have at the end of 1995 becomes a factor in the battery salvage values.

Yearly dependent costs (license, insurance, registration, etc.) are calculated for years 1985-1990 and 1991-1995 to reflect the diminished value of the vehicle.

Inclusion of the above considerations into. or in conjunction with, the equations listed in Section II gives the basis for component cost calculations. Program organization of these components is covered in the general description of the program.

LYFECC - GENERAL DESCRIPTION

LYFECC computes the life cycle cost of any specified number of vehicles for a 10-year span. Included in operating cost are maintenance, repair, fuel, and battery replacement (all mileage dependent); and insurance, license, registration and taxes (age dependent). Life cycle cost is operating cost plus vehicle acquisition costs and minus vehicle and battery salvage values.

There are two cost cases for each set of vehicle specifications. The first computes battery first purchase and replacement at 1.25 times OEM cost; the second at 2.0 times OEM cost.

Operating and life cycle costs are computed on an annual basis with year "0" reflecting initial acquisition costs only. Years 1 thru 10 reflect the cost of purchasing and operating.

Input printed included vehicle characteristics (i.e., weight, cost, battery weight, heat engine, and electric motor power, and fuel consumption rates), battery replacement information, and annual travel in kilometers.

Computation results printed are repair, maintenance, fuel (annually), and battery replacement costs; annual + per kilometer and annual, total + per kilometer discounted operating and life cycle costs.

COST ESTIMATING RELATIONS

I. OPERATING COSTS

A. Maintenance (¢/km)

1. Engine = .111818 + .003106 * HP
2. Chassis = .021742 + .000006 * TVW
3. Electric Motor = .037273 + .001242 * PHP
4. Battery = .000248 * BW
5. Flywheel = 0.0

B. Repair (¢/km)

1. Engine = .173939 + .004970 * HP
2. Chassis = .59015 + .000124 * TVW
3. Electric Motor = .05591 + .001242 * PHP
4. Accessories = .00005 * TVW
5. Transmission = .031061 + .000808 THP

C. Fuel (¢/km)

1. Gasoline = $(20.9 + .7479\Delta t) * (LT/KM)$
2. Diesel = $(19.36 + .6599\Delta t) * (LT/KM)$
3. Electricity = $(4.23 + .019\Delta t) * (KWH/KM)$

D. Yearly Costs

1. Years 0-6 = 33. + VPP * .01 + 125.
2. Years 5-10 = 33. + VPP * .006 + 75.

E. Battery Replacement

1. Battery replacement cost = 1.25 * BOEM
2. Battery replacement cost = 2.0 * BOEM

II. Life Cycle Costs

A. Vehicle Purchase Price = 2. * VC

B. Salvage

1. Vehicle = 0.1 * VPP
2. Batteries = .5 * BRC * RBL

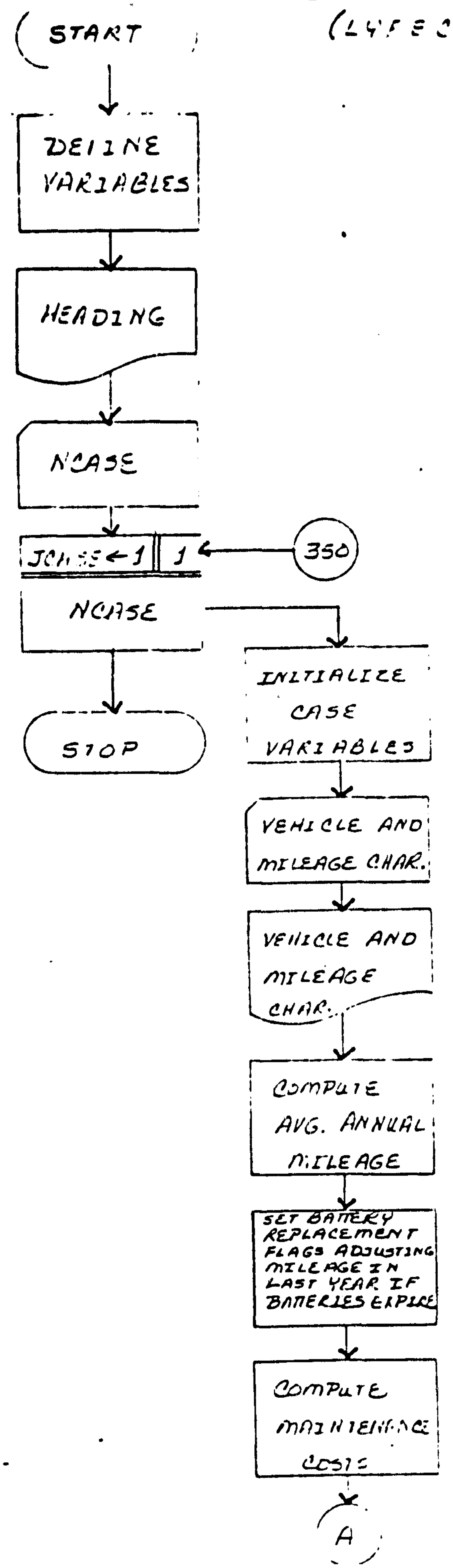
Symbols:

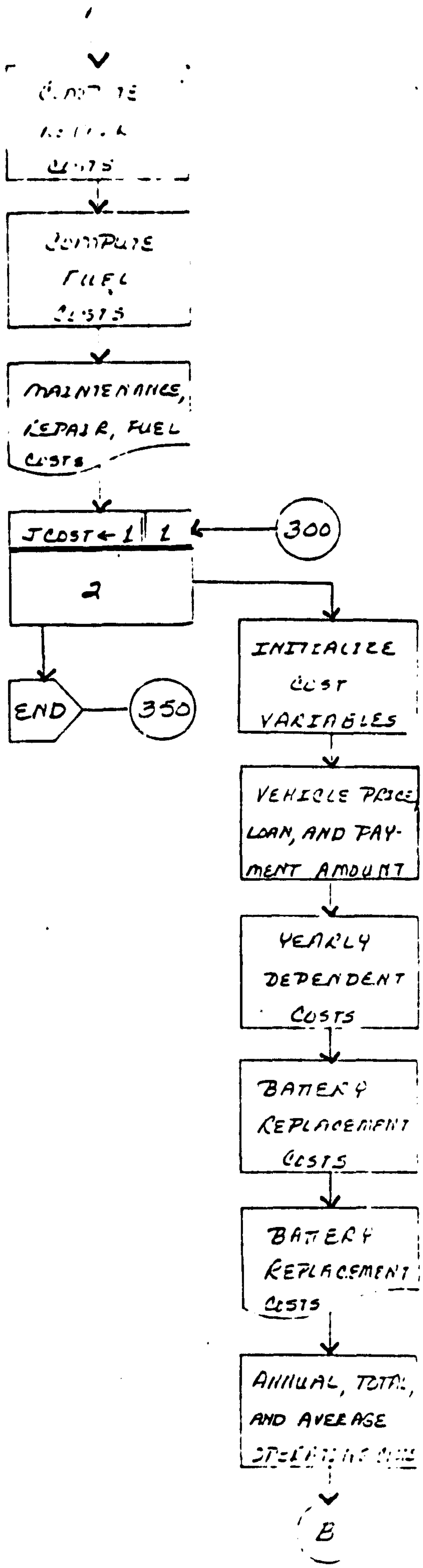
HP = Horse power of heat engine
TVW = Total Vehicle weight (KG)
PHP = Peak horse power of electric motor
BW = Battery Weight (KG)
THP = Total horse power thru transmission
VPP = Vehicle purchase price ($)
BOEM = Battery Manufacturing cost ($)
VC = Vehicle Manufacturing cost ($)
BRC = Battery replacement cost ($)
RBL = Remaining battery life

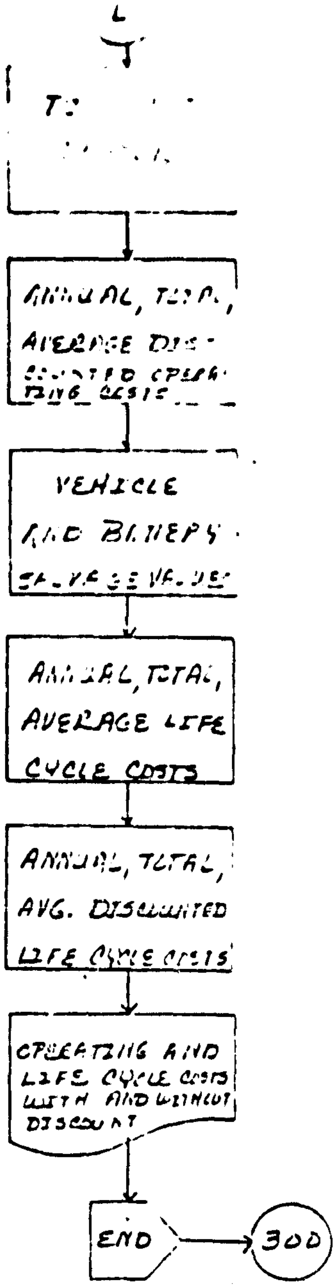
REFERENCES - APPENDIX A3

1. "Near Term Hybrid Passenger Vehicle Development Program - Phase I," (Assumptions and Guidelines), supplied by Jet Propulsion Laboratory, Pasadena, Calif.

2. Hybrid Vehicle Potential Assessment Interim Progress Report, Appendix C, Electric and Hybrid Cost Handbook, R. Heft, S. Heller, Draft #5030-162, Jet Propulsion Laboratory, Pasadena, Calif.


START
DEFINE VARIABLES
HEADING
NCASE
JCASE ← 1
1
350
NCASE
STOP
INITIALIZE CASE VARIABLES
VEHICLE AND MILEAGE CHAR.
VEHICLE AND MILEAGE CHAR.
COMPUTE AVG. ANNUAL MILEAGE
SET BATTERY REPLACEMENT FLAGS ADJUSTING MILEAGE IN LAST YEAR IF BATTERIES EXPIRE
COMPUTE MAINTENANCE COSTS
A


COMPUTE
FUEL
COSTS
MAINTENANCE,
REPAIR, FUEL
COSTS
JCOST ← 1
1
2
300
END
350
INITIALIZE
COST
VARIABLES
VEHICLE PRICE,
LOAN, AND PAY-
MENT AMOUNT
YEARLY
DEPENDENT
COSTS
BATTERY
REPLACEMENT
COSTS
BATTERY
REPLACEMENT
COSTS
ANNUAL, TOTAL,
AND AVERAGE
B


VEHICLE
AVERAGE LIFE
CYCLE COSTS
AVG. DISCOUNTED
OPERATING AND
LIFE CYCLE COSTS
WITH AND WITHOUT
DISCOUNT
END
300

[illegible]

EQUATIONS	[illegible]	UNITS	COMMENTS
	AL	$	[illegible]
	ALBR	$	BATTERY REPLACEMENT LOAN AMOUNT
	ALCCK	$	AVG. LIFE CYCLE COST PER KM.
	AOC	$	ANNUAL OPERATING COST (VECTOR)
	AOCK	$	AVERAGE OPERATING COST PER KM
	AP	$	CAR LOAN PAYMENT AMOUNT
	APBR	$	BATTERY REPLACEMENT LOAN PAYMENT AMOUN
	ACC	¢	ACCESSORIES REPAIR COST
	AVKT	KM	AVG. ANNUAL VEHICLE KM. TRAVELED (NATIONAL AVERAGE)
	BMC	¢	BATTERY MAINTENANCE COSTS
BOEM	BOEM	$	BATTERY MANUFACTURING COSTS
	BR	KM	KM. TALLY FOR BATTERY REPLACEMENT
BRC	BRC	$	BATTERY REPLACEMENT COST
	BRK	KM	LIFE EXPECTANCY OF BATTERIES
	BSV	$	BATTERY SALVAGE VALUE
	CMC	¢	CARRIAGE MAINTENANCE COST
	CRC	¢	CARRIAGE REPAIR COST
VC	CV	$	VEHICLE COST
	DAOC	$	DISCOUNTED ANNUAL OPERATING COST (VECTOR
	DF	–	DISCOUNT FACTOR
	DLCCK	$	DISCOUNTED LIFE CYCLE COST PER KM
	DOCK	$	DISCOUNTED OPERATING COST PER KM.
	DYLCC	$	DISCOUNTED ANNUAL LIFE CYCLE COST
	EFCK	¢	ANNUAL ELECTRICITY COST PER KM (VECT
	EKPY	KM	ADJUSTED ANNUAL KM. TRAVELED (VECTOR
	EKT	KM	AVG. ANNUAL VEHICLE KM. TRAVELED-PASSEN... CAR FORECAST, U.S.A. (VECTOR)
	EKWHPK	KWH/KM	ELECTRICITY CONSUMPTION RATE
	EMMC	¢	ELECTRIC MOTOR MAINTENANCE COST
	EMRC	¢	ELECTRIC MOTOR REPAIR COST
	FMC	¢	FLYWHEEL MAINTENANCE COST
	GDPK	LT/KM	DIESEL FUEL CONSUMPTION
	GGPK	LT/KM	GASOLINE FUEL CONSUMPTION
	HEMC	¢	HEAT ENGINE MAINTENANCE COST
	HERC	¢	HEAT ENGINE REPAIR COST
	KBR	–	BATTERY REPLACEMENT FLAG (VECTOR)
	NCASE	–	NUMBER OF CASES TO BE EXECUTED
	PDP	–	PERCENTAGE DOWN PAYMENT
	PFCK	¢	ANNUAL PETROLEUM COST PER KM (VECT
HP	PHE	KW	HEAT ENGINE POWER

[illegible]

EQUATIONS	PROGRAM	UNITS	DEFINITIONS
THP	[illegible]	KW	[illegible]
PP	PV	$	VEHICLE PRICE
	RKF	-	KM. REPAIR FACTOR
	TAOC	$	TOTAL ANNUAL OPERATING COST
	TDLCC	$	TOTAL DISCOUNTED LIFE CYCLE COST
	TDOC	$	TOTAL DISCOUNTED OPERATING COST
	TFCK	¢	TOTAL ANNUAL FUEL COST PER KM (VECTOR
	TK	KM	TOTAL KM (10 YEARS)
	TLCC	$	TOTAL LIFE CYCLE COST
	TMCK	¢	TOTAL MAINTENANCE COST PER KM
	TRC	¢	TRANSMISSION REPAIR COST
	TRCK	¢	TOTAL REPAIR COST PER KM
	TRCKF	¢	TOTAL REPAIR COST PER KM * KM. REPAIR [illegible] (VECTOR)
	VKT	KM	ANNUAL VEHICLE KM. TRAVELED - NATIONAL AVERAGE (VE[illegible]
	VSV	$	VEHICLE SALVAGE VALUE
BW	WB	KG	BATTERY WEIGHT
TVW	WV	KG	VEHICLE WEIGHT
	YDC	$	YEARLY DEPENDENT COSTS
	YDC1	$	YEARLY DEPENDENT COSTS (YEARS 1-5)
	YDC2	$	YEARLY DEPENDENT COSTS (YEARS 6-10)
	YLCC	$	ANNUAL LIFE CYCLE COST (VECTOR)

PROGRAM LISTING

```
      PROGRAM LYFECC
      INTEGER KBR(11)
      REAL EKPY(11),RKF(11),TRCKF(11),AOC(11),YLCC(11),OF(11),OAOC(11),
     1DYLCC(11),  VKT(11),EKPYZ(11),PFCK(11),TFCK(11),EFCK(11)
C
C     PRINT HEADING
C
      PRINT 500
      READ 400,NCASE
C
C     CASE LOOP
C
      DO 350 JCASE=1,NCASE
      TK=0.
      BR=0.
      DO 5 J=1,11
      KBR(J)=0
    5 CONTINUE
C
C     INPUT
C
      READ 410,CV,WV,WB,PHE,PM,PDP
      READ 410,GGPK,GDPK,EKWHPK,BOEM,BRK
      READ 410,(VKT(J),J=1,11),AVKT,EKT
      READ 410,(RKF(J),J=1,11)
      PRINT 510
      PRINT 520,CV,WV,WB,PHE,PM,PDP
      PRINT 530
      PRINT 520,GGPK,GDPK,EKWHPK,BRK,BOEM
C
C     MILEAGE
C
      FACT=EKT/AVKT
      DO 10 J=1,11
      EKPY(J)=FACT*VKT(J)
   10 CONTINUE
C
C     SET BATTERY REPLACEMENT FLAG
C
      DO 15 J=1,10
      BR=BR+EKPY(J)
      TK=TK+EKPY(J)
      IF(BR.LT.BRK)GO TO 15
      KBR(J)=1
      BR=BR-BRK
   15 CONTINUE
      IF(BR+EKPY(11).LE.BRK.OR.PM.EQ.0.)GO TO 18
      EKPY(11)=BRK-BR
      BR=BRK
      GO TO 19
   18 BR=BR+EKPY(11)
   19 TK=TK+EKPY(11)
      PRINT 533
      PRINT 534
      PRINT 530,(EKPY(J),J=1,11),TK
```

```
C
C      MAINTENANCE COSTS
C
       HEMC=PHE/.746*.003106+.111818
       CMC=HV*.000006+.021742
       EMMC=PM/.746*.001242+.037273
       IF(PM.EQ.0.)EMMC=0.
       BMC=WB*.000248
       FMC=0.
       TMCK=HEMC+CMC+EMMC+BMC+FMC
C
C      REPAIR COST
C
       HERC=PHE/.746*.00497+.173939
       CRC=HV*.000124+.59015
       EMRC=PM/.746*.00124+.05591
       IF(PM.EQ.0.)EMRC=0.
       ARC=HV*.00005
       TRC=(PHE+PM)/.746*.000808+.031061
       TRCK=HERC+CRC+EMRC+ARC+TRC
       DO 20 J=1,11
       TRCKF(J)=TRCK*RKF(J)
    20 CONTINUE
C
C      FUEL COST
C
       IF(GGPK.EQ.0)GO TO 30
       DO 25 J=1,11
       PFCK(J)=(20.9+.7479*(J-1))*GGPK
       EFCK(J)=(4.23+.049*(J-1))*EKWHPK
    25 TFCK(J)=PFCK(J)+EFCK(J)
       GO TO 36
    30 DO 35 J=1,11
       PFCK(J)=(19.36+.6599*(J-1))*GDPK
       EFCK(J)=(4.23+.049*(J-1))*EKWHPK
    35 TFCK(J)=PFCK(J)+EFCK(J)
    36 PRINT 540
       PRINT 550,HEMC,CMC,EMMC,BMC,FMC,TMCK
       PRINT 560
       PRINT 550,HERC,CRC,EMRC,ARC,TRC,TRCK
       PRINT 570
       PRINT 571
       PRINT 572,(PFCK(J),J=1,11)
       PRINT 573,(EFCK(J),J=1,11)
       PRINT 574,(TFCK(J),J=1,11)
C
C      COST LOOP
C
       DO 300 JCOST=1,2
       TAOC=0.
       AOCK=0.
       TDOC=0.
       DOCK=0.
       TLCC=0.
       ALCCK=0.
```

```
      TOLCC=0.
      DLCCK=0.
C
C     PAYMENTS
C
      PV=CV*2.
      IF(JCOST.EQ.1)PV=(PV-2.*BOEM)+1.25*BOEM
      AL=PV-PV*PDP
      AP=(AL+AL*.065*4.)/4.
C
C     YEARLY DEPENDENT COST
C
      YDC1=30.+PV*.01+125.
      YDC2=30.+PV*.006+75.
C
C     BATTERY REPLACEMENT COST
C
      BRC=2.*BOEM
      IF(JCOST.EQ.1)BRC=1.25*BOEM
      ALBR=BRC-BRC*PDP
      APBR=(ALBR+ALBR*.065*3.)/3.
      PRINT 575
      PRINT 576
      PRINT 590,BRC,ALBR,APBR,BR
C
C     OPERATING COSTS
C
      AOC(1)=YDC1
      YDC=YDC1
      DO 40 J=2,11
      IF(J.GE.7)YDC=YDC2
      AOC(J)=(TMCK+TRCKF(J)+TFCK(J))/100.*EKPY(J)+YDC
   40 CONTINUE
      AOC(11)=AOC(11)-YDC2
      DO 50 J=1,11
      IF  (KBR(J).EQ.0)GO TO 50
      L=J+2
      DO 60 K=J,L
      IF(K.GT.11)GO TO 50
      AOC(K)=AOC(K)+APBR
   60 CONTINUE
   50 TAOC=TAOC+AOC(J)
      AOCK=TAOC/TK
C
C     DISCOUNT FACTOR
C
      DF(1)=1/(1+.01)
      DO 70 J=2,11
      DF(J)=1/(1+.02)**J
   70 CONTINUE
C
C     DISCOUNTED OPERATING COSTS
C
      DO 80 J=1,11
      DAOC(J)=AOC(J)*DF(J)
```

```
)705        80 TDOC=TDOC+DACC(J)
)710           DOCK=TDOC/TK
         C
         C     LIFE CYCLE COSTS COMPONENTS
         C
)711           VSV=.01*PV
)713           BSV=.5*BRC*(1.-BR/BRK)
         C
         C     LIFE CYCLE COSTS
         C
)720           YLCC(1)=AOC(1)+PV*POP
)723           YLCC(11)=AOC(11)-BSV-VSV
 726           TLCC=YLCC(1)+YLCC(11)
 730           DO 90 J=2,10
 732           YLCC(J)=AOC(J)
 734           IF(J.GE.2.AND.J.LE.5)YLCC(J)=YLCC(J)+AP
 747        90 TLCC=TLCC+YLCC(J)
 754           ALCCK=TLCC/TK
         C
         C     DISCOUNTED LIFE CYCLE COSTS
         C
 756           DO 100 J=1,11
 757           DYLCC(J)=YLCC(J)*DF(J)
 762       100 TDLCC=TDLCC+DYLCC(J)
 765           DLCCK=TDLCC/TK
         C
         C     OUTPUT
         C
 /             PRINT 535,JCOST
 7,-           PRINT 580
 000           PRINT 591
 004           PRINT 590,(AOC(J),J=1,11),TAOC,AOCK
 022           PRINT 595
 026           PRINT 591
 032           PRINT 590,(DAOC(J),J=1,11),TDOC,DOCK
 050           PRINT 600
 054           PRINT 591
 060           PRINT 590,(YLCC(J),J=1,11),TLCC,ALCCK
 076           PRINT 610
 102           PRINT 591
 106           PRINT 590,(DYLCC(J),J=1,11),TDLCC,DLCCK
 124           PRINT 550,PV,AL,AP,YOC1,YOC2,BRC,VSV,BSV
 150       300 CONTINUE
 152       350 CONTINUE
 155           STOP
 157       400 FORMAT(7I10)
 157       405 FORMAT(1H0,10I4)
 157       410 FORMAT(7E10.4)
 157       500 FORMAT(1H1,*LIFE CYCLE COST ESTIMATION*)
 157       510 FORMAT(1H1,*VEHICLE CHARACTERISTICS*/9X,*COST*,11X,*HEIGHT*,7X,*BA
              1TTERY WT.*,3X,*HEAT ENG. RATING*,1X,*ELEC. MOTOR RATING*,2X,*% DOW
              1N*)
  7        520 FORMAT(1H ,8E16.6)
 ..        530 FORMAT(1H ,5X,*GAS LT/KM*,6X,*DIESEL LT/KM*,8X,*KWH/KM*,4X,*BATTER
              1Y REPLACE/KM*,4X,*BOEM*)
```

```
1157      533 FORMAT(1H0,*ANNUAL MILEAGE*)
1157      534 FORMAT(1H ,4X,*YEAR 0*,4X,*YEAR 1*,4X,*YEAR 2*,4X,*YEAR 3*,4X,*YE
             1R 4*,4X,*YEAR 5*,4X,*YEAR 6*,4X,*YEAR 7*,4X,*YEAR 8*,4X,*YEAR 9*,
             1X,*YEAR 10*,4X,*TOTAL*)
1157      535 FORMAT(1H0,*COST CASE=*,I2)
1157      540 FORMAT(1H0,*MILEAGE DEPENDENT COSTS(CENTS/KM)*/2X,*MAINTENANCE*/
             15X,*HEAT ENGINE*,7X,*CHASSIS*,7X,*ELEC. MOTOR*,7X,*BATTERY*,5X,*FL
             1YWHEEL*,06X,*TOTAL*)
1157      550 FORMAT(1H ,8F15.4)
1157      560 FORMAT(1H ,1X,*REPAIR*/5X,*HEAT ENGINE*,7X,*CHASSIS*,7X,*ELEC. MO
             1OR*,5X,*ACCESSORIES*,5X,*TRANSMISSION*,4X,*TOTAL*)
1157      570 FORMAT(1H ,1X,*FUEL*)
1157      571 FORMAT(1H+,17X,*YEAR 0*,4X,*YEAR 1*,4X,*YEAR 2*,4X,*YEAR 3*,4X,*YE
             1AR 4*,4X,*YEAR 5*,4X,*YEAR 6*,4X,*YEAR 7*,4X,*YEAR 8*,4X,*YEAR 9*,
             13X,*YEAR 10*)
1157      572 FORMAT(1H ,2X,*PETROLEUM*,2X,12F10.4)
 157      573 FORMAT(1H 2X,*ELECTRICITY*,12F10.4)
1157      574 FORMAT(1H ,2X,*TOTAL*,6X,12F10.4)
 157      575 FORMAT(1H0,*BATTERY REPLACEMENT*)
 157      576 FORMAT(1H ,3X,*BR COST*,3X,*BR LOAN*,2X,*BR PAYMT*,1X,*MILEAGE-LAS
             1T BATTERY SET*)
 157      580 FORMAT(1H ,*ANNUAL OPERATING COSTS*)
 157      590 FORMAT(1H ,12F10.2,F10.5)
 157      591 FORMAT(1H ,4X,*YEAR 0*,4X,*YEAR 1*,4X,*YEAR 2*,4X,*YEAR 3*,4X,*YEA
             1R 4*,4X,*YEAR 5*,4X,*YEAR 6*,4X,*YEAR 7*,4X,*YEAR 8*,4X,*YEAR 9*,3
             1X,*YEAR 10*,4X,*TOTAL*,5X,*PER KM*)
 157      595 FORMAT(1H0,*DISCOUNTED ANNUAL OPERATING COSTS*)
   7      600 FORMAT(1H0,*LIFE CYCLE COSTS*)
 1        610 FORMAT(1H0,*DISCOUNTED LIFE CYCLE COSTS*)
 157          END
```

TYPICAL PROGRAM CUTPUT

```
VEHICLE CHARACTERISTICS
       COST              WEIGHT          BATTERY WT.    HEAT ENG. RATING ELEC. MOTOR RATING  % DOWN
    4.670400E+03     2.102000E+03     3.780000E+02    4.579000E+01    3.053000E+01     3.000000E-01
     GAS LT/KM       DIESEL LT/KM          KWH/KM     BATTERY REPLACE/KM     NOFM
    4.500000E-02     0.                2.167000E-01    9.549100E+04     7.560000E+02

ANNUAL MILEAGE
   YEAR 0    YEAR 1     YEAR 2     YEAR 3     YEAR 4     YEAR 5     YEAR 6     YEAR 7     YEAR 8     YEAR 9    YEAR 10     TOTAL
    0.00  34299.43  28773.40  25533.95  23247.37  21532.38  20007.96  18674.13  17530.76  16570.09  15815.00 221993.39

MILEAGE DEPENDENT COSTS(CENTS/KM)
 MAINTENANCE
   HEAT ENGINE        CHASSIS          ELEC. MOTOR        BATTERY          FLYWHEEL        TOTAL
        .3025            .0344              .0081            .0937          0.0000           .5187
 REPAIR
   HEAT ENGINE        CHASSIS          ELEC. MOTOR      ACCESSORIES       TRANSMISSION     TOTAL
        .4796            .0500              .1667            .1051             .1137          1.6553
 FUEL             YEAR 0     YEAR 1     YEAR 2     YEAR 3     YEAR 4     YEAR 5     YEAR 6     YEAR 7     YEAR 8     YEAR 9    YEAR 10
  PETROLEUM        .9405      .9742     1.0078     1.0415     1.0751     1.1088     1.1424     1.1761     1.2097     1.2434     1.2771
  ELECTRICITY      .9166      .9273      .9379      .9485      .9591      .9697      .9804      .9910     1.0016     1.0122     1.0229
  TOTAL           1.8571     1.9014     1.9457     1.9900     2.0342     2.0785     2.1228     2.1671     2.2113     2.2556     2.2999

BATTERY REPLACEMENT
   BR COST   BR LOAN  BR PAYMT MILEAGE-LAST BATTERY SET
   945.00    661.50    263.50  31011.39

COST CASE= 1
ANNUAL OPERATING COSTS
   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
   242.74   1055.52   1123.20   1196.06   1461.44   1410.33   1200.83    960.29    926.42   1081.30    709.20  11503.56     .05182

DISCOUNTED ANNUAL OPERATING COSTS
   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
   240.34   1052.90   1050.49   1104.97   1323.67   1259.43   1115.04    826.42    775.10    887.11    570.44  10214.09     .04601

LIFE CYCLE COSTS
   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
  2874.93   3030.10   3057.94   3130.72   3396.10   1410.33   1200.83    960.29    926.42   1081.30    302.48  21467.59     .09670

DISCOUNTED LIFE CYCLE COSTS
   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
  2846.46   2912.52   2881.56   2892.30   3075.95   1259.43   1115.04    826.42    775.10    887.11    243.20  19715.26     .08881
     8773.9606      6141.7720      1934.6582       242.7396       157.6430       945.0000       87.7396      319.0522

BATTERY REPLACEMENT
   BR COST   BR LOAN  BR PAYMT MILEAGE-LAST BATTERY SET
   1512.00   1058.40   421.60  31011.39

COST CASE= 2
ANNUAL OPERATING COSTS
   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
   248.41   1101.19   1128.95   1201.73   1625.21   1512.10   1442.33    971.69    929.82   1242.89    867.37  12341.69     .05559

DISCOUNTED ANNUAL OPERATING COSTS
   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
   245.95   1058.43   1053.83   1110.21   1472.00   1404.86   1255.63    829.33    778.03   1019.60    697.60  10935.40     .04926

LIFE CYCLE COSTS
   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
  3850.70   3160.80   3180.63   3261.41   3684.89   1582.10   1442.33    971.69    929.82   1242.89    263.40  22770.01     .10261

DISCOUNTED LIFE CYCLE COSTS



   YEAR 0    YEAR 1    YEAR 2    YEAR 3    YEAR 4    YEAR 5    YEAR 6    YEAR 7    YEAR 8    YEAR 9   YEAR 10     TOTAL      PER KM
  3020.49   3030.13   3004.72   3013.04   3337.52   1434.86   1255.63    829.33    778.03   1019.60    211.91  20913.26     .09421
     9340.9600      6530.6720      2659.6817       248.4096       161.0450      1512.0000       93.4800      310.4436
```

APPENDIX A4

LTD OPTIONS AND AMENITIES

FORD LTD

OPTIONS

Add your personal touch.

Audio

Ford LTD offers a newer, wider selection of factory-installed radios and audio equipment than ever. All are precision engineered and built to exacting Ford quality standards. For details, get the booklet "Dimensions in Sound" at your Ford Dealer's.

- ☐ AM Radio. Five pushbuttons for quick tuning. Instrument panel speaker.
- ☐ AM/FM Monaural Radio. AM and FM programming in a moderately priced entertainment package.
- ☐ AM/FM Stereo Radio.* Stereo indicator light. Controls for 4-speaker mix adjustment.
- ☐ AM/FM Stereo Radio with 8-Track Tape Player.*
- (A) Electronic AM/FM Stereo Search Radio with Quadrasonic Tape Player* Your preferred station choices (five AM, five FM) can be stored in the radio's electronic memory bank and selected by sensitive touch-buttons. Or scan feature can provide 8-second samples of each listenable station until you make your choice. Quartz crystal allows precise tuning. Quadrasonic tape player gives you an entertainment alternative.
- ☐ AM/FM Stereo Radio with Cassette Tape Player.* Listen to compact cassettes (up to 60 minutes).
- (B) 40 Channel CB Radio. Automatically scans for active channel. Will override radio front speakers sending or receiving; so you can listen to AM or FM programs and still pick up CB signal. Controls mounted in hand mike which disconnects for security. (Chassis mounted in trunk.) Available with all LTD factory-installed sound systems. Comes with fixed AM/FM/CB tri-band antenna. FCC license application included.
- ☐ Dual Rear Seat Speakers.
- ☐ Premium Sound System. Separate power amplifier (two with Quadrasonic tape player) and more sensitive rear speakers improve the sound of any LTD AM/FM stereo radio.

*Four speakers, with fader control, included.

Appearance

- ☐ Color-Keyed Deluxe Belts. Include tension eliminator feature. Std. Landau and Squire. (Pages 10-11.)
- ☐ Exterior Accent Group. See page 6.
- ☐ Interior Luxury Group. See pages 10-11.
- ☐ Rocker Panel Moldings. Available for Country Squire. Shown on LTD Wagon (see page 9).
- ☐ Dual Accent Paint Stripes. Bodyside decor. See pages 2, 3, 4, 5, 6, 7.
- ☐ Metallic Glow Paint. Red Glow (2H), Medium Blue Glow (3H), Camel Glow (8J). See Cover, pages 2, 5, 6, 9.
- ☐ Tu-Tone Paint/Tape Treatment. Four combinations offered. Available on all sedans and LTD Wagon.
- ☐ Vinyl Roof. 10 colors. (Std. on Landaus.) Full roof on LTD's (no cost option on Landau 2-Dr.) Rear half roof on LTD 2-Dr. only.
- ☐ Luggage Compartment Trim. Luxuriously finished in 12 oz. carpeting.

Comfort

- ☐ SelectAire Conditioner provides year-round comfort (heating, cooling, ventilating) with manual controls.
- (C) SelectAire Conditioner with Automatic Temperature Control. You select the inside temperature, thermostatic controls help maintain it.
- ☐ Tinted Glass—Complete. Reduces heat and glare of the sun. Recommended with air conditioner.
- ☐ Dual Facing Rear Seats. See page 9.
- ☐ Dual Flight Bench Seat Recliners. Permit separate adjustment of driver and passenger seat backs.
- ☐ Split Bench Seats. Individually adjustable, each has recliner and folding armrest. See pages 10-11.
- ☐ Deluxe Sound Insulation Package (std. on Landau and Squire) and Luxury Sound Insulation Package. Your Ford Dealer can give you full details on these two separate options.

Convenience

- ☐ Convenience Group. Includes: interval windshield wipers, visor vanity mirror, remote control decklid release (sedans), electric tailgate lock (wagons), trip odometer, "low fuel" and "low washer fluid" warning lights
- ☐ Electric Clock (Std. in Landau and Squire.)

(D) Electronic (Date/ET) Digital Clock. Detailed under "B" page 11.

(E) Electric Rear Window Defroster. Quickly melts ice or snow, defogs inside surface.

☐ Front Cornering Lamps. Side lighting for dark corners. (Pages 2, 5, 8.)

(F) Illuminated Entry System. Lifting door handle illuminates keyhole, switches on inside lights.

☐ Dual Note Horn. Std. on Landau and Squire.

☐ Light Group. Front courtesy lights, dual beam map light, plus lights in engine compartment, trunk or cargo area (std. Landau and Squire), rear door (and doorgate) courtesy switches (std. Landau 4-Door and Squire), "headlamps on" warning buzzer.

☐ Deluxe Luggage Rack. (Pages 8-9.)

☐ Illuminated Visor Vanity Mirror. Grooming aid; adjustable lighting intensity.

☐ Dual Remote Control Mirrors. Driver can aim both mirrors.

☐ LH Remote Control Mirror. Aimed from inside by door-mounted control.

(G) Fingertip Speed Control. Lets you set and hold any speed above 30 mph. Resume feature reestablishes speed after braking. All controls blended into styling of luxury steering wheel.

(H) Tilt Steering Wheel. Adjusts to five positions. In full "up" position eases entry and exit.

☐ Conventional Spare Tire. (Std. on wagons.)

Interiors

☐ For seats and trims, see pages 10-11.

Performance

☐ Optional Axle Ratio.

☐ Engine Option. 5.8 litre (351 CID) V-8. (Required on wagons with California emission system.)

☐ Handling Suspension. Higher capacity springs, shocks; heavier front stabilizer bar & rear bar, 6½-in. wheels.

☐ Heavy-Duty Battery.

☐ Adjustable Level Air Shock Absorbers. Compensate for heavy loads.

☐ Heavy-Duty Suspension. Higher capacity springs and shock absorbers

(I) Heavy-Duty Trailer Towing Package. Gives LTD a 6000-lb rating. Includes trailer towing suspension and frame, HD cooling system, rear brakes, frame and battery, 60-amp. (minimum) alternator, special wiring harness, trailer towing axle, 6½-in. wheels.

Power Assists

(J) Power Lock Group. Includes: power door locks and remote control decklid release in sedan glove box; power tailgate lock on wagons.

☐ Power Radio Antenna. Electrically raises antenna or lowers it.

☐ Power Seats. Six-way adjustment. On bench seat, flight bench, split bench seats (driver only or dual control.)

(K) Power Side Windows. On 4-door and wagon models, include lock-out switch so only driver can operate all windows.

Protection

☐ Vinyl Insert Bodyside Moldings.

☐ Lower Bodyside Protection (in addition to Ford corrosion protection measures noted on the back cover), offers an application of vinyl under the paint along the lower sides of the body to help provide extra protection against stone pecking. Especially important when traveling on gravel roads or where use of road salt is heavy.

☐ Bumper Guards. Front, rear or both; include bumper grilles.

☐ Bumper Rub Strips. Help protect bumpers and guards. (Shown on all display models.)

☐ Protection Group. Door edge guards, color-keyed carpet floor mats, license plate frame(s).

(L) The Ford Extended Service Plan, backed by Ford Motor Company and honored by participating Ford Dealers nationwide, is available to provide longer protection than your car's basic warranty against specified major component repairs. Consult your salesman for full details

Tires

☐ Black or white sidewall tires in a choice of sizes. Consult your Ford Dealer for the tires best suited to your kind of driving.

Wheel Covers

☐ Luxury Wheel Covers (4). See page 8.

☐ Wire Wheel Covers (4). See pages 2, 4, 5, 6.